RAMS v6.0+
New Features, Future Plans, Current Apps
2008

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ATmospheric, Meteorological and Environmental Technologies

Developments for v6.0

- General release – January 2006
- New vertical coordinate (ADAP)
- Land surface scheme (LEAF) improvements
- Data assimilation schemes
- FDDA schemes
- History initialization option
- 1-way nest
- E-eps, E-l schemes from Silvia @ CNR, Torino
- Kain-Fritsch cumulus parameterization
- HDF5 file formats
- Continued transition to Fortran 90
- Lambert-Conformal projection

Double precision time

- To allow longer climate runs
  - Current single precision variable can run into problems after ~ 120 days on 32-bit machines
  - Double precision will allow ~ 3,000,000 years (if timestep is > 1sec)
  - Minor changes to RAMS and post-processing apps

RRTM Radiation schemes

- US-government funded software from AER, Inc.
- Validated by using line-by-line models
- Shortwave scheme uses up to 35 species (usually 7, O2, CO, CO2, etc.), 16 bands, clouds, aerosols
- Longwave scheme implemented in MM5 and WRF and is reasonable speed.
- BIG problem: original code takes 6 seconds per column on Athlon! Will investigate speed-ups

RRTM Radiation schemes

- However, AER released “GCM” versions of shortwave and longwave schemes
- Now much faster, fast enough for general use

CARMA Radiation schemes

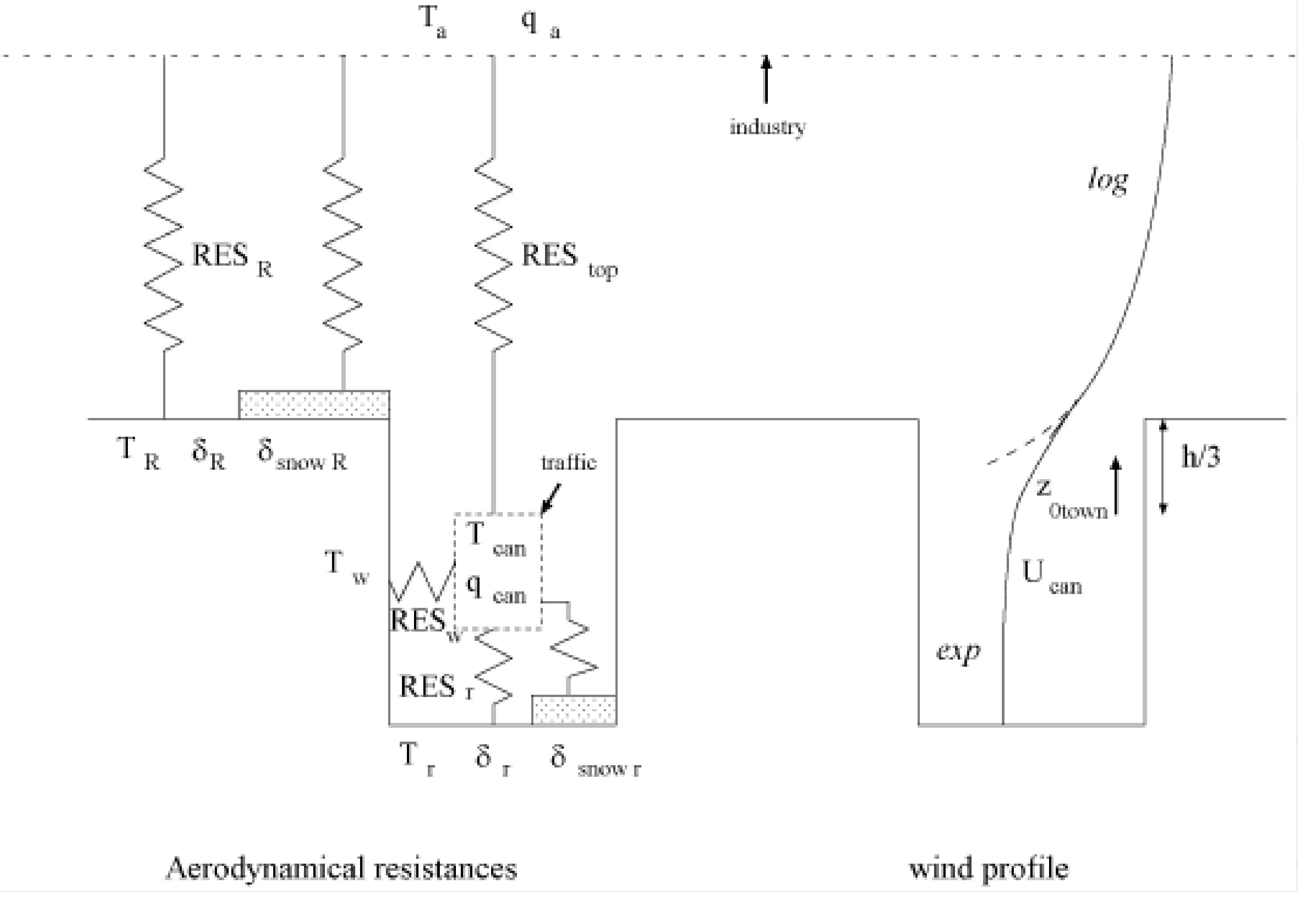
- From NASA
- Implemented by CPTEC in Brazil
- More sophisticated schemes which handle aerosols, etc.
- Reasonable execution speeds

TEB Urban Canopy

- Developed by Valery Masson from Meteo-France, we have received permission to distribute as part of RAMS
- Treats urban area as subgrid-scale entity
- Three surfaces: roofs, roads, walls
- Following figures from Meteo-France web site…

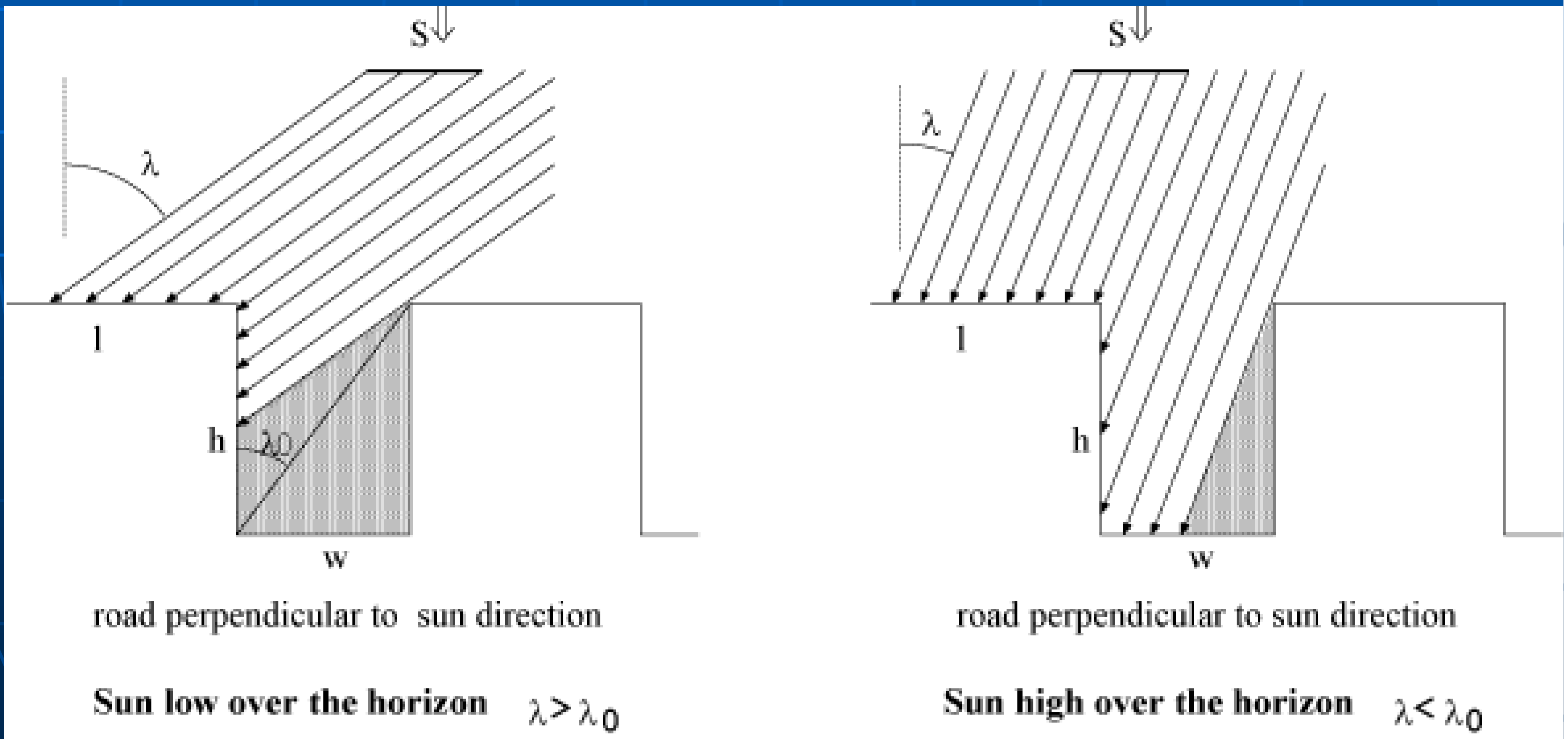
TEB Urban Canopy Features

Processes:



TEB Urban Canopy Features

Radiation:



TEB Urban Canopy Features

Inputs:

symbol	designation of symbol	unit
geometric parameters		
a_{town}	fractional area occupied by artificial material	-
a_{bld}	fractional artificial area occupied by buildings	-
$1 - a_{bld}$	fractional artificial area occupied by roads	-
h	building height	m
h/l	building height/width ratio	-
h/w	canyon height/width ratio[1]	-
Ψ_r	sky-view factors for road: $\Psi_r = [(h/w)^2 + 1]^{1/2} - h/w$	-
Ψ_w	sky-view factors for one wall: $\Psi_w = \frac{1}{2}\{h/w + 1 - [(h/w)^2 + 1]^{1/2}\}/(h/w)$	-
$z_{0_{town}}$	dynamical roughness length for the buildings/canyons system	m
radiative parameters		
$\alpha_R, \alpha_r, \alpha_w$	roof, road and wall albedos	-
$\epsilon_R, \epsilon_r, \epsilon_w$	roof, road and wall emissivities	-
thermal parameters		
$d_{R_k}, d_{r_k}, d_{w_k}$	thickness of the k^{th} roof, road or wall layer	m
$\lambda_{R_k}, \lambda_{r_k}, \lambda_{w_k}$	thermal conductivity of the k^{th} roof, road or wall layer	$Wm^{-1}K^{-1}$
$C_{R_k}, C_{r_k}, C_{w_k}$	heat capacity of the k^{th} roof, road or wall layer	$Jm^{-1}K^{-1}$

TEB Urban Canopy Features

Computed:

symbol	designation of symbol	unit
prognostic variables		
T_{R_k}, T_{r_k}, T_{w_k}	temperature of the k^{th} roof, road or wall layer	K
W_R, W_r	roof and road water interception reservoir	kgm^{-2}
$W_{snow\,R}$, $W_{snow\,r}$	roof and road snow interception reservoir	kgm^{-2}
$T_{snow\,R}$, $T_{snow\,r}$	roof and road snow temperature	K
$\rho_{snow\,R}$, $\rho_{snow\,r}$	roof and road snow density	kgm^{-3}
$\alpha_{snow\,R}$, $\alpha_{snow\,r}$	roof and road snow albedo	-
diagnostic variables		
T_{can}	canyon air temperature	K
q_{can}	canyon air specific humidity	kg/kg
U_{can}	along canyon horizontal wind	ms^{-1}
α_{town}	town effective albedo	-
$T_{s_{town}}$	town area averaged radiative surface temperature	K
input energy fluxes		
$L^{\downarrow}$	downwards infra-red radiation on an horizontal surface	Wm^{-2}
$S^{\downarrow}$	downwards **scattered** solar radiation on an horizontal surface	Wm^{-2}
$S^{\Downarrow}$	downwards **direct** solar radiation on an horizontal surface	Wm^{-2}
$H_{traffic}$	anthropogenic sensible heat flux released by in the canyon	Wm^{-2}
$LE_{traffic}$	anthropogenic latent heat flux released by the canyon	Wm^{-2}
$H_{industry}$	anthropogenic sensible heat flux released by industries	Wm^{-2}
$LE_{industry}$	anthropogenic latent heat flux released by industries	Wm^{-2}
other energy input		
$T_{i_{bld}}$	building interior temperature	K
output energy fluxes		
S^*_R, S^*_r, S^*_w	net solar radiation budget for roofs, roads and walls	Wm^{-2}
L^*_R, L^*_r, L^*_w	net infra-red radiation budget for roofs, roads and walls	Wm^{-2}
H_R, H_r, H_w	turbulent sensible heat flux for roofs, roads and walls	Wm^{-2}
LE_R, LE_r, LE_w	turbulent latent heat flux for roofs, roads and walls	Wm^{-2}
$G_{R_{k,k+1}}$, $G_{r_{k,k+1}}$, $G_{w_{k,k+1}}$	conduction heat flux between k^{th} and $k+1^{th}$ roof, road or wall layers	Wm^{-2}
H_{town}	town averaged turbulent sensible heat flux	Wm^{-2}
LE_{town}	town averaged turbulent latent heat flux	Wm^{-2}

ISAN Replacement

- Project in 2005 to perform review of current state of 3DVAR, 4DVAR, and Ensemble Kalman Filter and tested WRF 3DVAR scheme
- Expected to recommend general usage of WRF 3DVAR (it has been advertised so much!)
- But… group funding the study (AFTAC) needs data analyses for past events
- 3DVAR relies on error matrices, statistical relationship between grid point values and observations. Can be thought of as smoothing weights.
- Best if error matrices computed from a historical set of runs (like in operational settings).
- Not available for past runs. Ensembles can be generated, but if we need an ensemble, easier to use EKF scheme.

ISAN Replacement

- So…we decided to pursue an existing data analysis package that ingests a wide range of current observations…
- LAPS – Limited-area Analysis and Prediction System
- Developed at NOAA/FSL (Now NOAA/ESRL/GSD (Earth System Research Laboratory/Global Systems Division)

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LAPS slides from:

Local Data Assimilation and Modeling Applicable to NWS WFO Operations

Brent L. Shaw *
Local Analysis and Prediction Branch
Forecast Research Division
NOAA Forecast Systems Laboratory

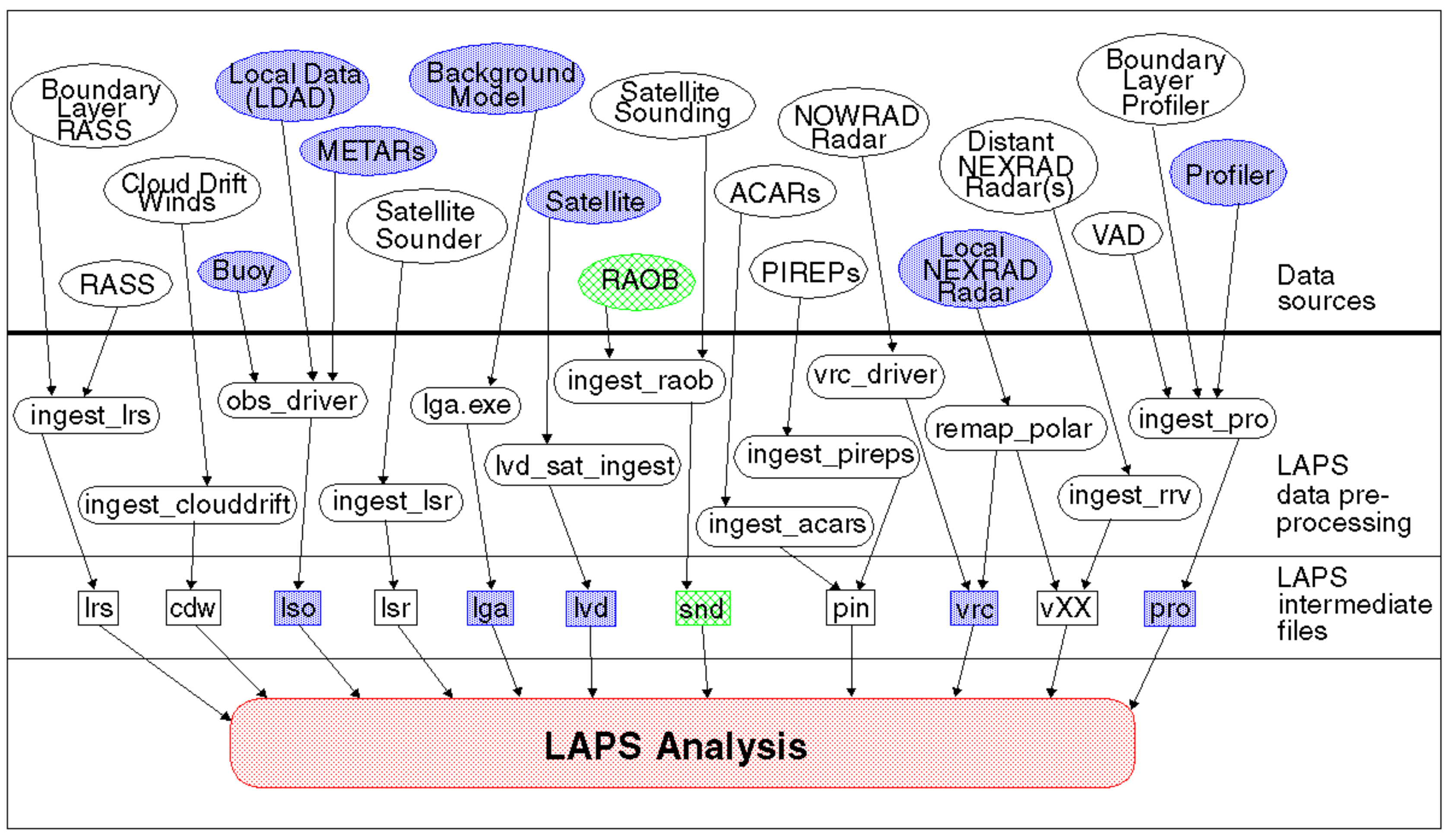
LAPS Analysis Components

- Raw data ingest and quality control
- Analysis of state variables
  - Temperature
  - Winds
  - Moisture
- Cloud analysis
- Diagnostic variables
- Dynamic balance

Data Ingest

- Use all available sources
  - National data
    - Model grids from RUC or Eta for first-guess fields
    - METARs, satellite, wind profilers, ACARS, RAOBs, etc.
  - ***Local data*** - Often not available to national data assimilation systems!
    - Highway departments
    - Agricultural networks
    - Amateur radio (APRS) network
    - Universities
    - Private industries
    - Experimental data sources

Data Ingest

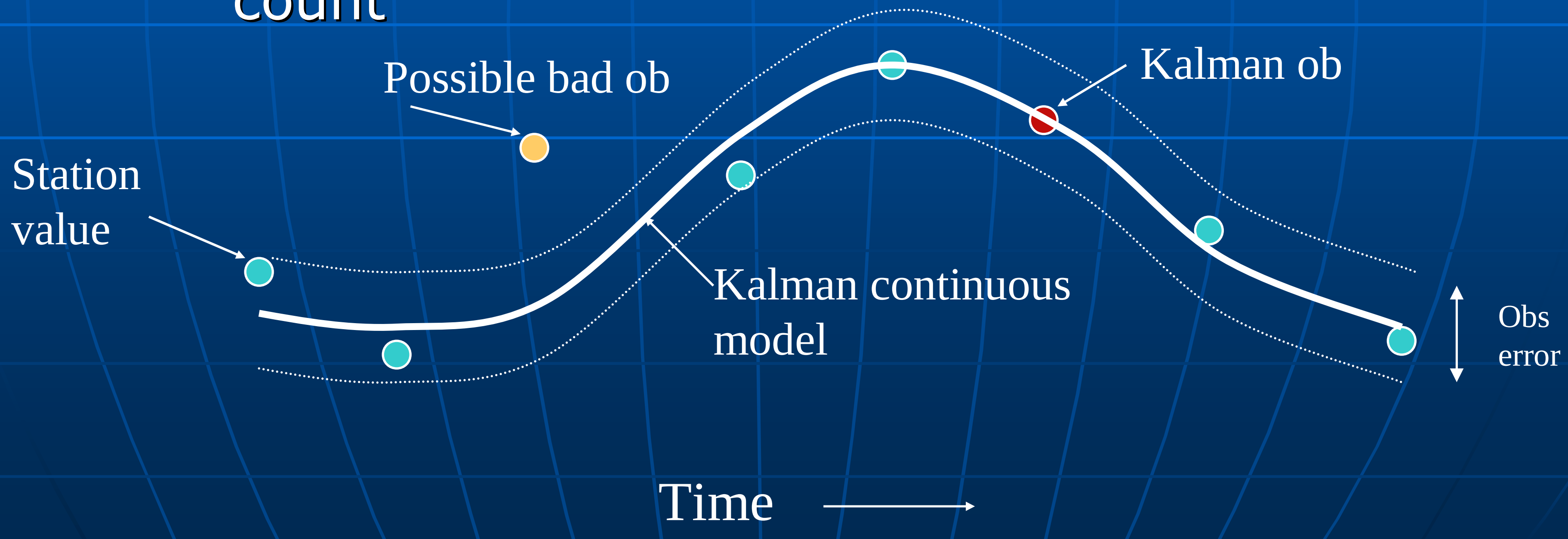

Boundary Layer RASS
Local Data (LDAD)
Background Model
Satellite Sounding
NOWRAD Radar
Distant NEXRAD Radar(s)
Boundary Layer Profiler
METARs
Cloud Drift Winds
Satellite Sounder
Satellite
ACARs
Profiler
VAD
Buoy
RASS
RAOB
PIREPs
Local NEXRAD Radar
Data sources
ingest_lrs
obs_driver
lga.exe
ingest_raob
vrc_driver
remap_polar
ingest_pro
lvd_sat_ingest
ingest_pireps
ingest_clouddrift
ingest_lsr
ingest_acars
ingest_rrv
LAPS data pre-processing
lrs
cdw
lso
lsr
lga
lvd
snd
pin
vrc
vXX
pro
LAPS intermediate files
LAPS Analysis

Quality Control

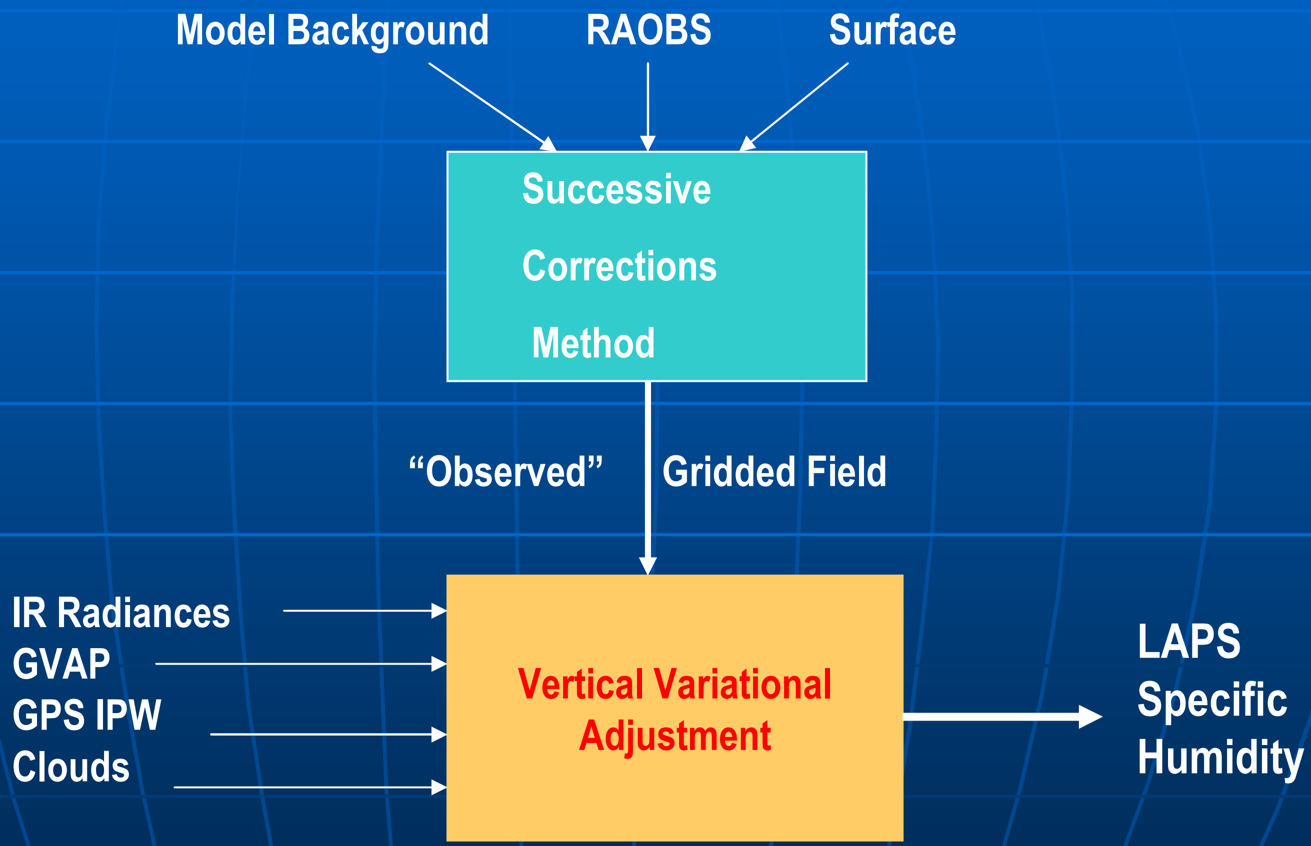
- Local data sets present QC challenges:
  - Poor siting
  - Poor maintenance
  - Poor communications
- Result: Inaccurate, irregular observations, leading to inconsistent analysis products and poor forecast initialization

Solution: Kalman Filter

- Provides a continuous station estimate of observation based on self trend, buddy trends, and NWP – use for quality checking
- With missing obs – maintain constant station count



Moisture Analysis



Moisture Analysis

Variational Adjustment

Minimize

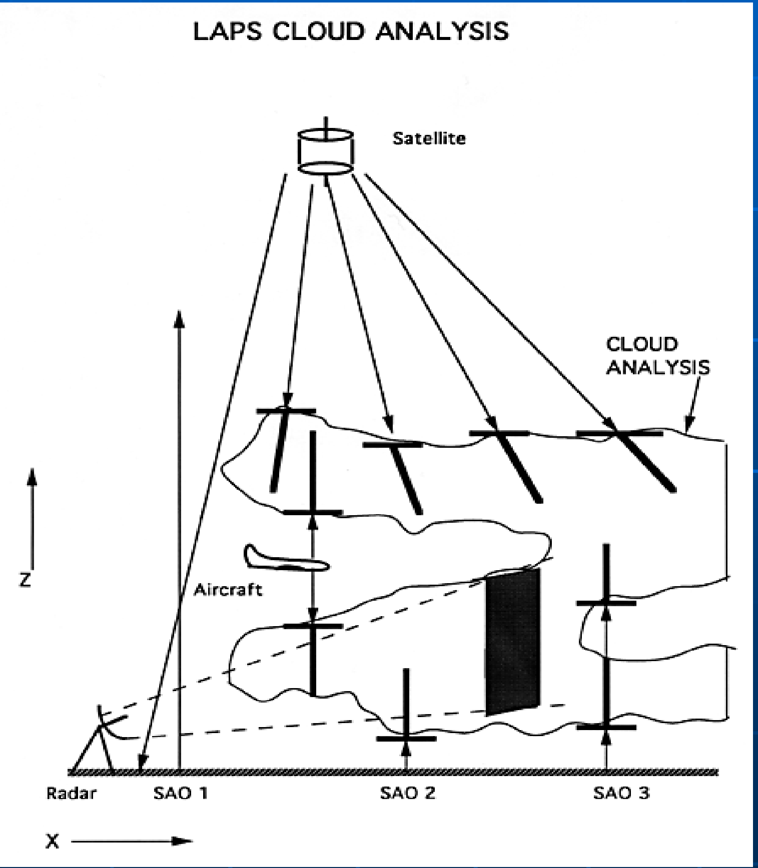
$$J = \sum_{i=1}^{n_{chan}} (R_i(T, O_3, cq) - R_i^o)^2 / E_{i,rad}^2 + (\sum_{k=1}^{n_{lvl}} c_k q_k - Q_{gps}^o)^2 / E_{gps}^2$$

$$+ \sum_{j=1}^{n_{gvap}} (\sum_{k=1}^{n_{lvl}} P_{jk} c_k q_k - Q_j^o)^2 / E_{j,gvap}^2 + \sum_{k=1}^{n_{lvl}} C_k (c_k q_k - q_s(T))^2 / E_{k,cld}^2$$

$$+ \sum_{k=1}^{n_{lvl}} (1 - c_k)^2 * E_{k,adj}^2 / E_{k,obs}^2$$

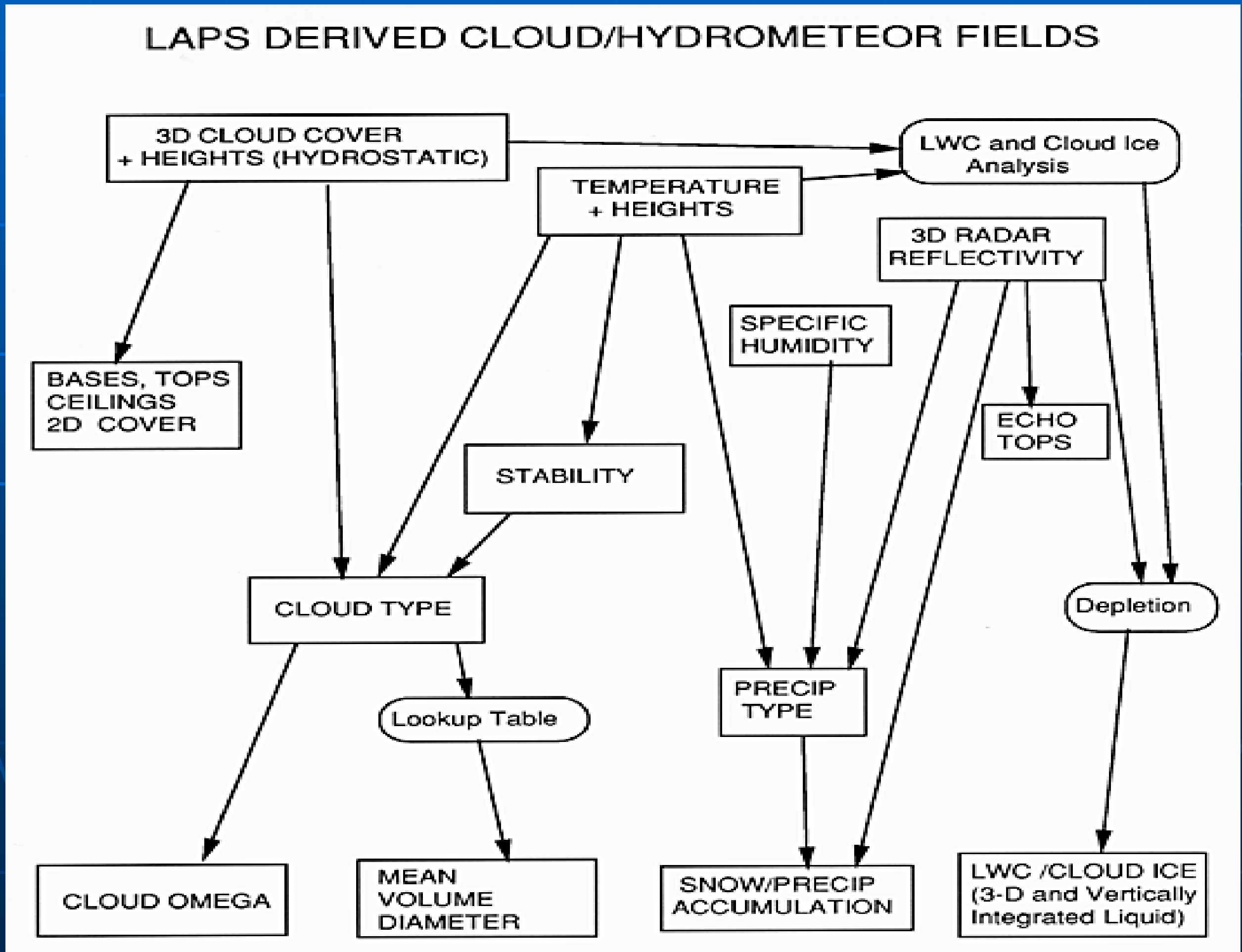
Solve for c_k

Cloud Analysis Scheme



- Uses satellite (Vis and IR)
- Aircraft observations
- Surface observations
- Radar
- Interpolates cloud obs to grid
- Cloud feeds back into water vapor analysis

Cloud Model


LAPS DERIVED CLOUD/HYDROMETEOR FIELDS
3D CLOUD COVER + HEIGHTS (HYDROSTATIC)
LWC and Cloud Ice Analysis
TEMPERATURE + HEIGHTS
3D RADAR REFLECTIVITY
SPECIFIC HUMIDITY
BASES, TOPS CEILINGS 2D COVER
ECHO TOPS
STABILITY
CLOUD TYPE
Depletion
Lookup Table
PRECIP TYPE
CLOUD OMEGA
MEAN VOLUME DIAMETER
SNOW/PRECIP ACCUMULATION
LWC /CLOUD ICE (3-D and Vertically Integrated Liquid)

Dynamic Adjustment

- Final step required for consistency between cloud and moisture analysis and the mass and momentum fields
- Retrieval of "observed" cloud vertical motion from LAPS cloud analysis and a simple 1-D cloud model
- Integral variational analysis constrained by full equations of motion and continuity, allowing clouds to impact mass and motion fields
- Explicit representation of model background error over entire grid
- Adjustments are applied on increment from background field
- Minimization of time tendencies ensure smooth model start

Dynamic Balance Equations

Dynamic Balancing and Continuity Formalism

$$J=\sum_k\sum_j\sum_i O_V(\hat{u}-u')^2+O_V(\hat{v}-v')^2+O_\omega(\hat{\omega}-\omega_c')^2+O_\Phi(\hat{\Phi}-\Phi')^2$$

$$+\mu(\hat{u}_t)^2+\mu(\hat{v}_t)^2+\lambda(\hat{u}_x+\hat{v}_y+\hat{\omega}_p)$$

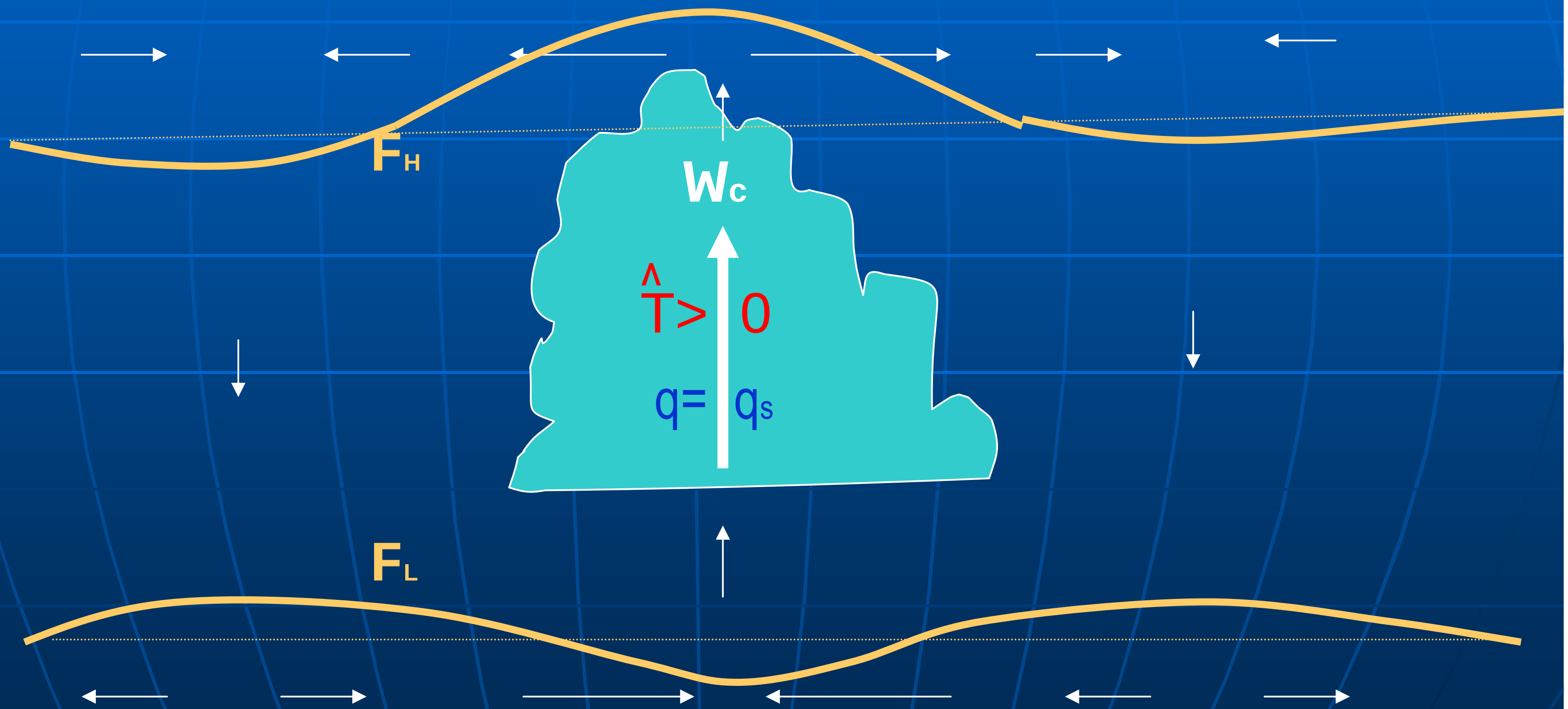
$$+B_V\hat{u}^2+B_V\hat{v}^2+B_\Phi\hat{\Phi}^2+B_\omega\hat{\omega}^2$$

$$\hat{u}_t=-(u_b\hat{u}_x+\hat{u}u_{bx}+v_b\hat{u}_y+\hat{v}u_{by}+\omega_b\hat{u}_p+\hat{\omega}u_{bp})-\hat{\Phi}_x+f\hat{v}-D(\hat{u})$$

$$\hat{v}_t=-(u_b\hat{v}_x+\hat{u}v_{bx}+v_b\hat{v}_y+\hat{v}v_{by}+\omega_b\hat{v}_p+\hat{\omega}v_{bp})-\hat{\Phi}_y-f\hat{u}-D(\hat{v})$$

( ) b are background quantities; (^) are solution increments from background;
( )' are observation differences from background

Cloud, Wind and Mass Dynamic Adjustment



Results of Analysis

- 3D Grids suitable for nowcasting
  - T, p, u, v, w
  - q_{vapor}, q_{cloud}, q_{rain}, q_{snow}, q_{ice}, $q_{graupel}$
  - Derived parameters
- Balance ensures suitability for *diabatic* model initialization
  - Hydrometeors initialized at t=0
  - Elimination of model spin-up problem!

LAPS Deficiencies (Features)

- Pressure vertical coordinate
- Uses a modified Barnes scheme for the majority of the variables
- LAPS can take significant time to execute.
- It can only handle one data time and one grid per execution.
- The code itself is broken into ~~38~~ 42 executables, each performing its own distinct task, with its own memory structure, etc. PERL scripts control processing.

LAPS Development Tasks

1) Separate ISAN completely from RAMS
   - Use ISAN as a top-level driver for the LAPS code
   - Set up a common memory structure
   - Handle the calling of the various LAPS components, which will be converted from separate executables to subroutines.
   - This structure will also handle executing multiple data times and grids.
   - MPI calls (mostly) at this level

   - Mostly finished

LAPS Development Tasks

2) Implement distributed memory parallelism (MPI) on the slowest LAPS components.
   - With a common memory structure, this task will be easier to implement and maintain.
   - MPI calls (mostly) at the driver lever.

LAPS Development Tasks

3) Implementation of a generalized height coordinate.
   - An “arbitrary” 3d array of heights defines the levels on which the processing is done. These heights can be defined in numerous ways: geopotential (to emulate pressure coordinates), terrain-following (as in RAMS), Cartesian, or any mixture that makes sense. WRF sigma-p coordinates should be able to be input easily.
   - Each LAPS component will need to be converted from the pressure coordinate to a height coordinate.
   - This cannot emulate isentropic coordinates, so we will explore the possibility of a hybrid coordinate.

   - Some LAPS components have been modified for a generalized pressure coordinate. We will explore this first.

LAPS Development Tasks

4) Explore Barnes alternatives.
   - Numerous possibilities
   - We will perform preliminary testing of various schemes, comparing with the current scheme, see how they perform, then implement the most reasonable.

   - Not sure we'll get to this…

LAPS Development Tasks

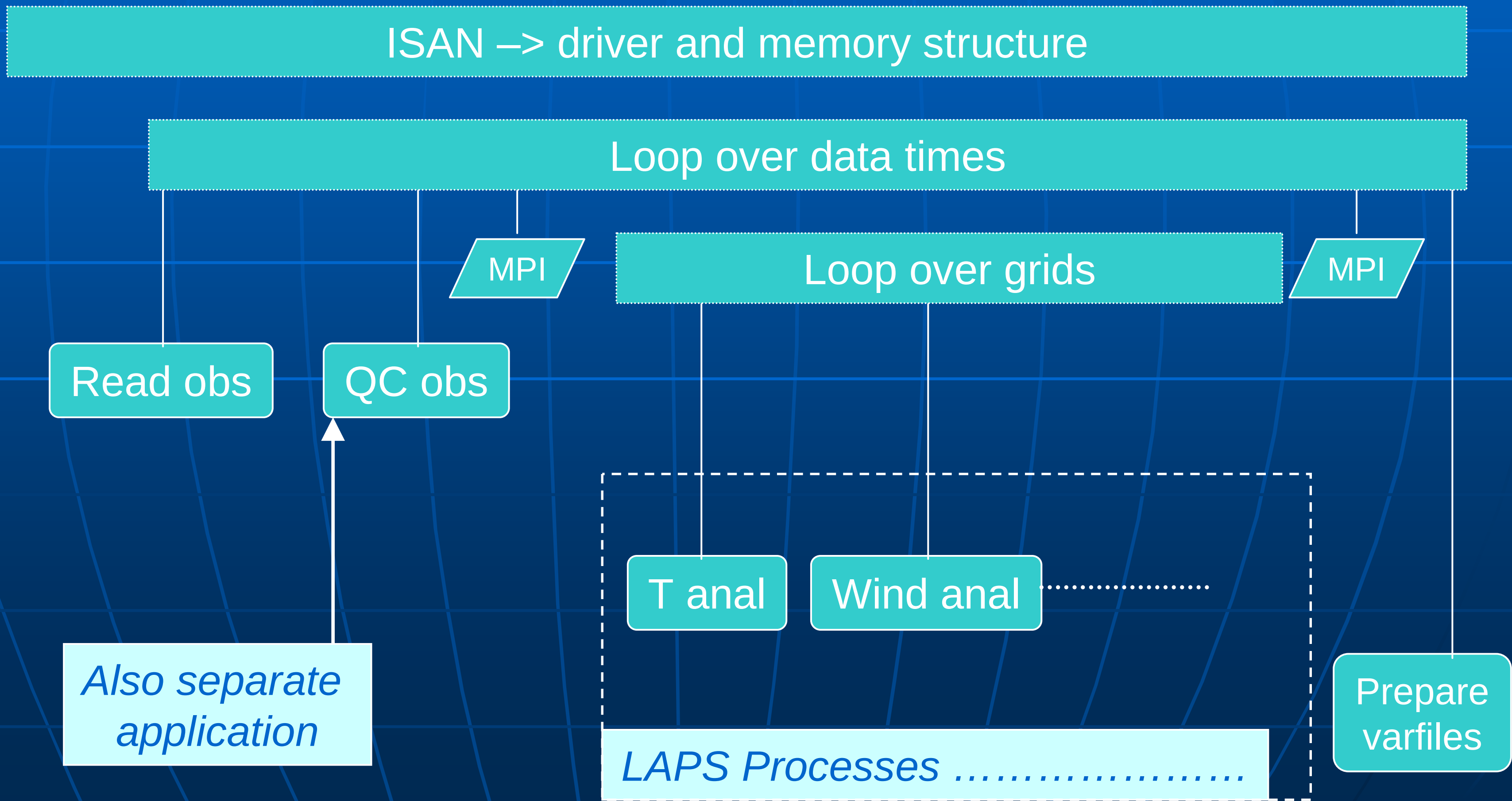
5) Observation file formats
   - LAPS uses various ASCII formats, different than the RAMS GDF (Ralph) formats.
   - Numerous other RAMS-related applications (ODA, revu_st, ODV, etc.) use the observational data directly
   - Either a set of converters will be necessary, or if possible, come into agreement with GSD on a common data format.

LAPS Development Tasks

6) Observation quality control

- Several types of quality control are done as part of the current LAPS processing.
- However, the QC is done as part of the LAPS processing stream, meaning that LAPS has to be run with the observational components activated.
- Configure the general QC components into a separate application.
- Can include the things in our standalone package along with the various LAPS techniques. The new (hopefully standardized) file formats would have QC flags, like the current Ralph format, which the individual applications can use.

LAPS New Structure Schematic



Current Applications

Wind forecasting for renewable energy

- Parques eólicos (wind farms)

Wind forecasting for renewable energy

- Spain has second most number of wind turbines in the world (US is first, but Spain has most per capita)
- Iberdrola has about 100 different sites where wind turbines are installed, covering much of Spain
- Sites provide a challenge; in usual forecasting case, we verify for stations located in valleys (where people live)
- Wind farms are located on small-scale topography, usually on tops of ridge lines
- Further, turbines are located higher above ground than most observations

Wind forecasting for renewable energy

- The challenge: produce hourly wind forecasts for small-scale (~ 1 km), complex topography, over a large area (1000 x 1000 km) with reasonable computer resources

Wind forecasting for renewable energy

- Configure RAMS to cover the entire Iberian Peninsula at a reasonable resolution (4km)
- Forecasts are run 3 times per day (0000, 1200, 1800 UTC)
- Complete automation of operational system from data collection to model execution to web site updating (real-time graphics and verifications).
- Wind forecasts are given to another algorithm to compute energy production
- But 4 km resolution will not adequately resolve the topography….

Wind forecasting for renewable energy

- Perform adjustments on the 4km model output:
  - Use a diagnostic wind model (CALMET) using RAMS fields and higher resolution topography
  - Configure RAMS in a “diagnostic” mode:
    - Each hour, run RAMS for 10 minutes at 100m grid spacing
    - High-resolution topography
    - Allow wind field to come into adjust with topography
  - Statistical adjustment of raw model output
  - So far, “diagnostic” RAMS is producing best wind forecast results

Operational forecast systems

- Computer hardware:
  - Linux "Beowulf" cluster
  - Dual Xeon nodes
  - RAMS – 24 nodes
  - Gigabit interconnect
  - 1.2 TByte disk storage
  - Second cluster runs diagnostic RAMS

Operational AQ forecast systems in Spain

Operational AQ forecast systems

- Regulations by some of the Spanish autonomous governments require air quality forecasting systems be implemented if new power plants are built
- If forecast pollution will exceed a certain level, decisions may be made to reduce output of power plants or industries in the region
- Two air quality forecasting systems are under development using RAMS (one with CAMx)

Operational AQ forecast systems

- Somewhat similar configuration to wind farm system
- Automated system:
  - Data collection and processing
  - Model execution (RAMS and CAMx)
  - Results and verifications posted on web site

Operational AQ forecast systems

- Forecasts 4 times per day (00, 06, 12, 1800 UTC), 36 hour forecasts
- Meteorological input data from NCEP in US
- RAMS grid configuration (40km, 10km, 2km, 500m)
- CAMx grid configuration (10km, 2km, 500m)
- Will be configured in assimilation mode, where current forecast will start from results of previous forecast

Operational AQ forecast systems

- Emissions most difficult part of accurate air quality forecasting. Using emissions from Corine-Aire dataset for Europe (50 km grid)
- Very little "observed" emission data to use; some point source information available from power plants
- Need to make assumptions to develop higher resolution gridded fields for CAMx
- Use of "surrogate" information (such as population) to redistribute emissions to higher spatial resolution

Episodic AQ simulations in Spain

- Episodic simulations are required by some autonomous governments when new power plants are built
- Equivalent of environmental impact statements required by some US states and EPA
- Over past five years, we have been involved in simulations for 10 locations
- More coming in next few months

Episodic AQ simulations

- Each location defines 3 episodes: low, medium, and high pollution levels
- Seven day runs are made of RAMS and CAMx, first 2 days are “spin-up” days
- Control run is defined as gridded emissions with all existing point sources active, as occurred at the time
- Numerous sensitivity runs of each episode look at impact of varying the number of plants active

Episodic AQ simulations

- RAMS and CAMx resolutions down to 1 km in some cases
- Focus on NO_x, O_3, PM10
- Emissions continue to be difficult
- Both Corine-Aire and EDGAR global emission dataset were used

Episodic AQ simulations

- General results show:
  - Ozone verification were good for summer, less accurate in winter (more transport from regions outside of CAMx domain)
  - PM values were lacking emissions from natural sources. Dust from Sahara can be significant.
  - NOx showed a general low bias. Currently investigating the reasons.

"New" Project

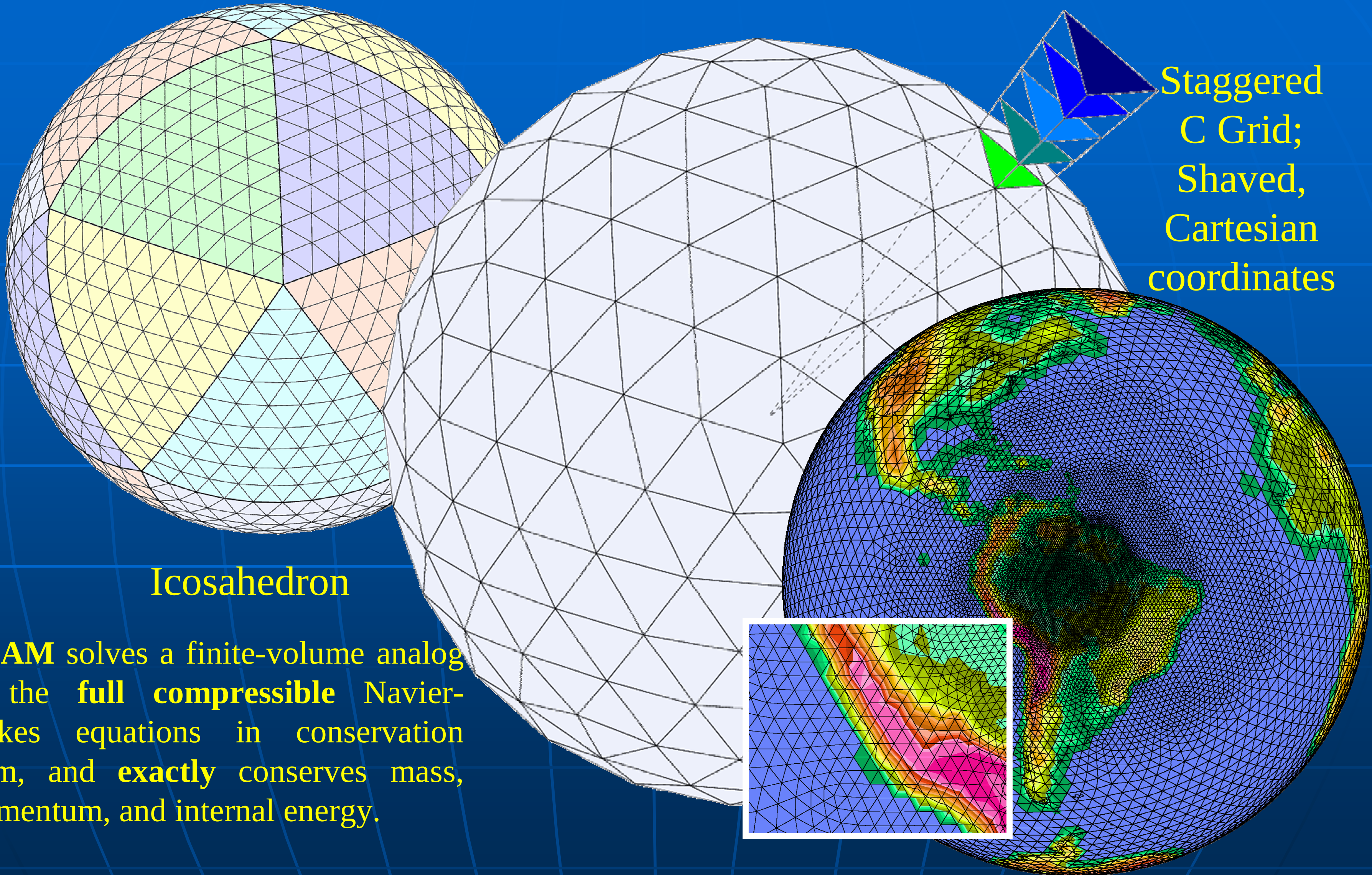
- Involving high-resolution forecasting in a target domain for a variety of applications
- Forecasting system will housed in a somewhat mobile platform
- 500m grid spacing for 100x100km domain
- If I told you more, I would have to kill you….

New/Current Developments

- OLAM – global/regional model (Duke)
- Universal code structure (ATMET, Duke, and CPTEC in Brazil)
- Numerous cloud microphysics improvements and additions (ATMET and Duke)
- Aerosols (U of Athens and ATMET)

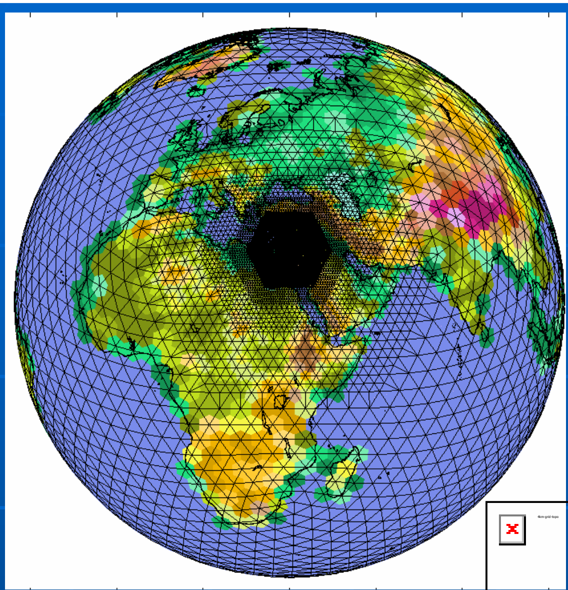
OLAM General Structure

- Ocean-Land-Atmosphere Model (OLAM), an expansion of RAMS into an Earth System Model
- Unstructured grid, arrays are not (i,j,k), but (i,k)
- Triangular mesh covering globe
- Smooth, continuous grid refinement from global to target region
- Shares common physics schemes and code with RAMS

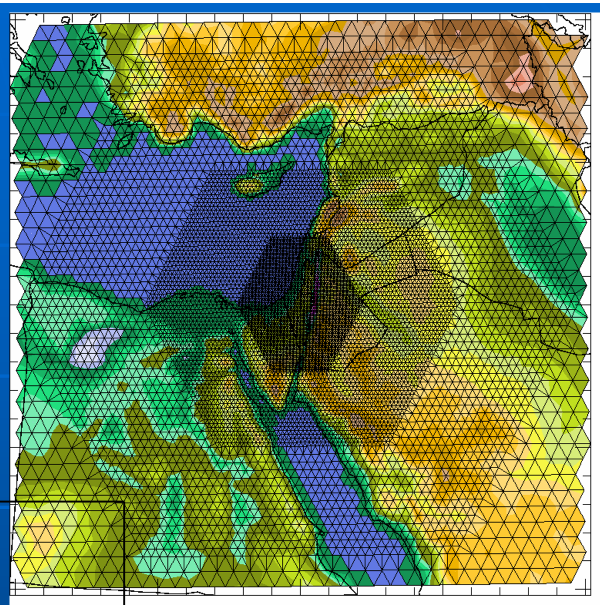


OLAM solves a finite-volume analog of the **full compressible** Navier-Stokes equations in conservation form, and **exactly** conserves mass, momentum, and internal energy.

Unstructured Grid; No overlapping grid cell; No special nest communication; Each cell communicates directly with its neighbor independently of resolution

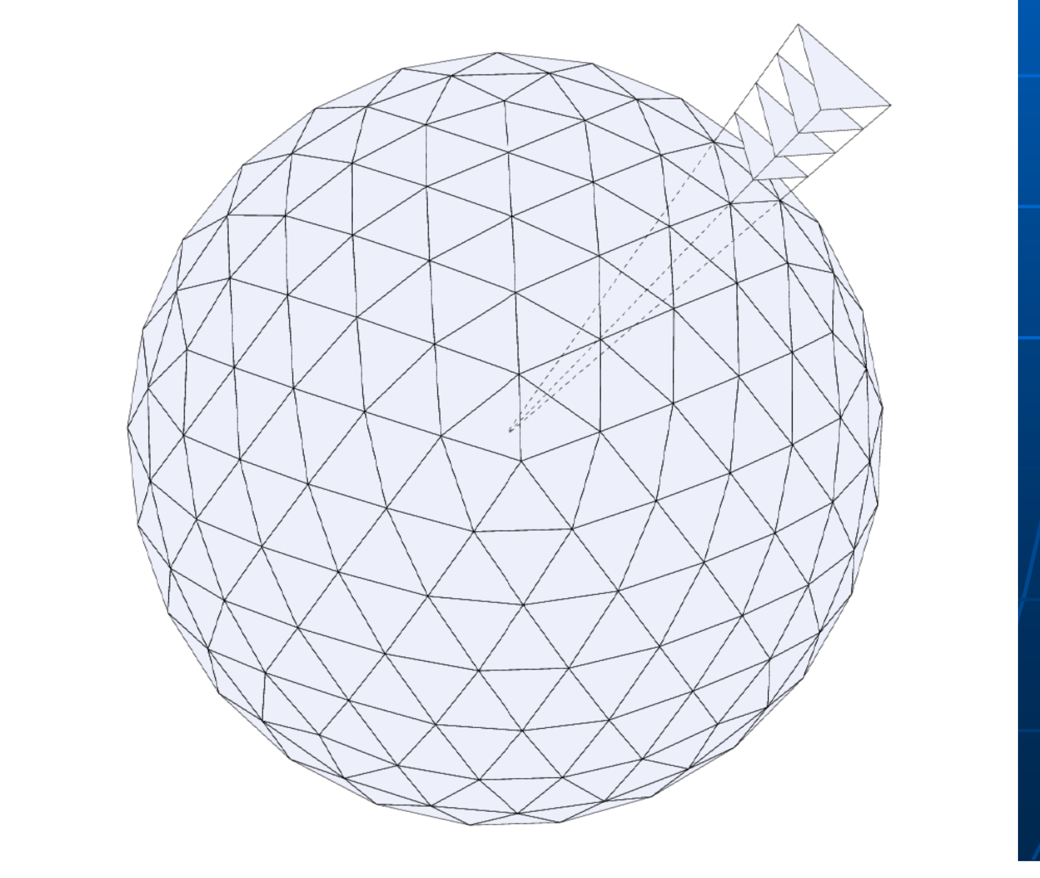


OLAM Grids and Topography



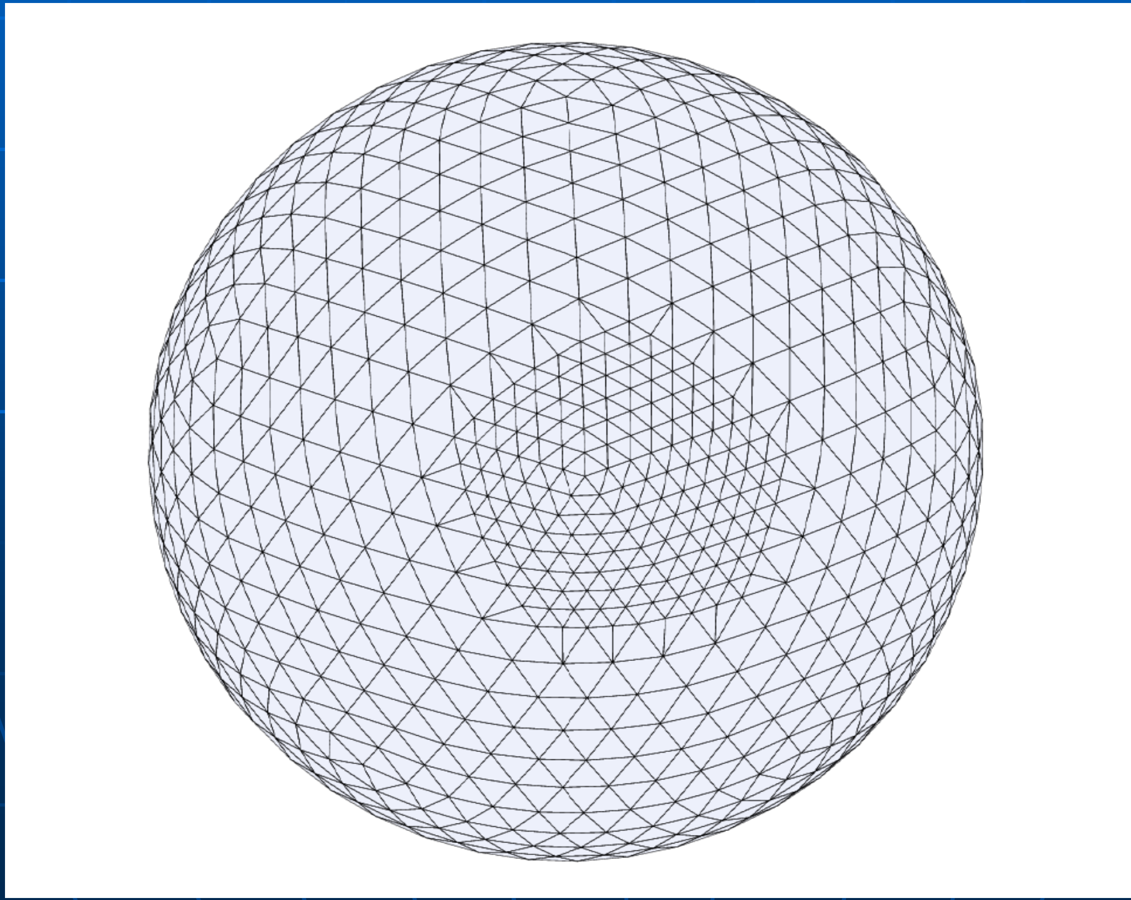
OLAM Grid Structure

Triangles in all vertical levels have same footprint
Cartesian coordinate system with origin at Earth center



OLAM Grid Structure

Local mesh refinement - no special nesting operation



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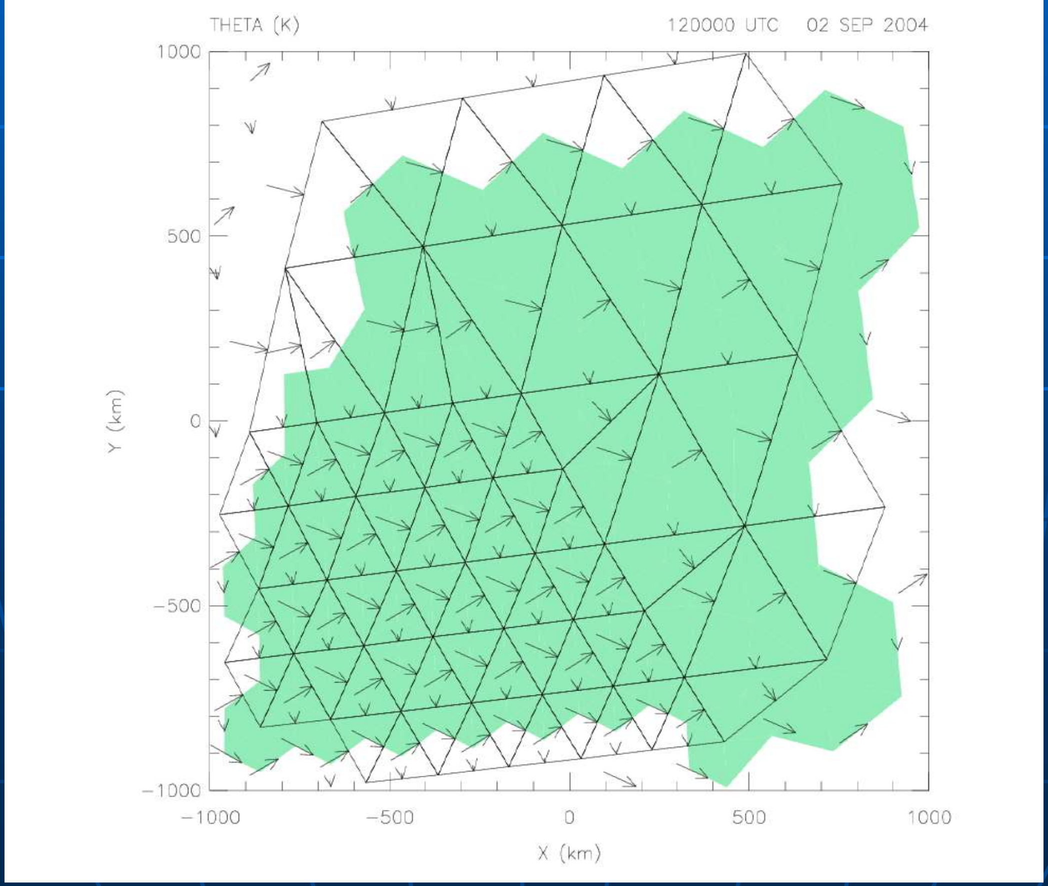
OLAM Grid Structure

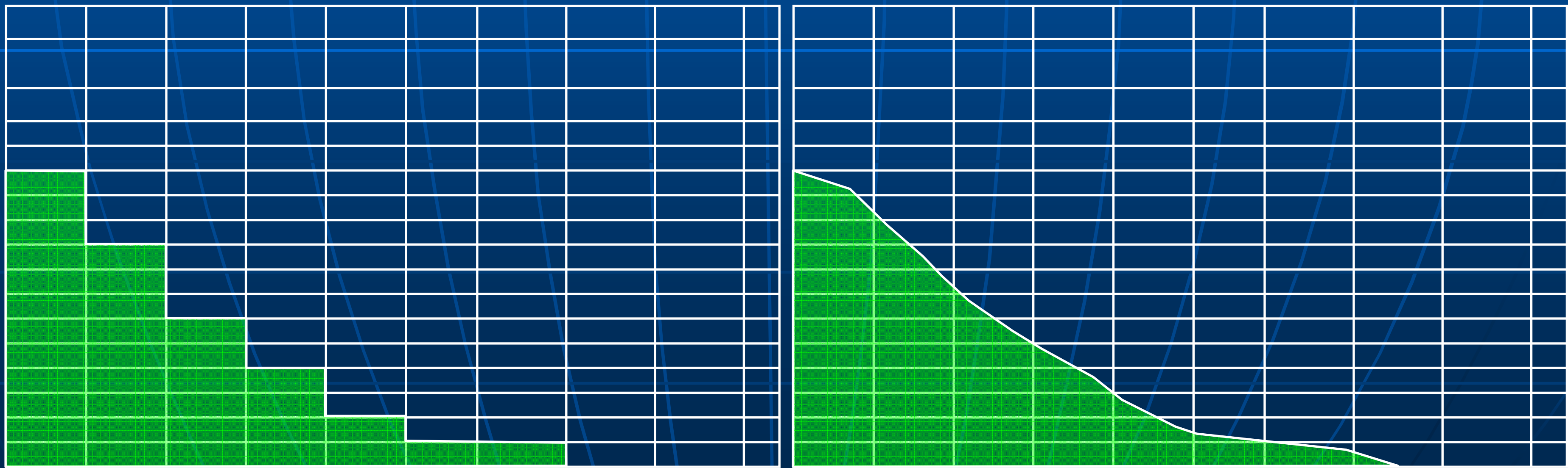
Local mesh refinement - no special nesting operation



Vertical coordinate for OLAM/RAMS

- ADAP (ADaptive APerature) coordinate
- Mostly following work of Adcroft, *et al* for oceanographic model
- “Shaved” ETA-type coordinate

Standard ETA coordinate ***ADAP coordinate***



Universal code structure

- In designing efficient code, numerous issues need to be considered. Our list:
  - Multiple model support
    - RAMS
    - OLAM
    - B-RAMS – Brazilian RAMS
  - Multiple machine architectures
    - PC clusters – distributed memory parallelism
    - SMP machines – shared memory parallelism
    - Clusters of SMP's – both
    - SMP vector supercomputers – parallelism with long "vector" lengths
  - Clarity and maintainability of code

Universal code structure

- Exploring techniques to accommodate all considerations
  - Not sure if we can satisfy all requirements
  - "Gather-scatter" technique shows promise from an efficiency point of view
    - An example: radiation scheme that works with columns
    - Gather a set of columns (> 1000), structure all arrays (horiz,vert)
    - Modify all loop over vertical to have an inner loop over horizontal dimension
  - Efficient, but makes code rather messy

Microphysics Improvements

- Already rather sophisticated, but why stop there!
- Colorado State University has used separate RAMS version for past 6 years (old RAMS v4.3, new micro)
- Our goal is integration of CSU RAMS modifications into RAMS v6.x

Improvements from CSU RAMS

- Explicit activation of CCN in two size ranges (CCN and GCCN via nucleation of cloud droplets based on a Lagrangian model developed by Feingold and Heymsfield,1992).
- Addition large cloud droplet mode: drizzle drops, generated by activation of GCCN by self collection of cloud droplets (in combination with the traditional single mode of cloud droplets allows a more accurate representation of the bimodal distribution that occurs in the atmosphere).
- Number concentrations of both cloud modes are prognostic variables as well as the CCN, GCCN, and IFN (ice-forming nuclei) concentrations (this eliminates the highly limiting constraint of selecting a constant mean diameter or a constant number concentrations.)

Improvements from CSU RAMS

- Microphysical and radiative effects of two modes of dust particles.
- Microphysical and radiative effects of two modes of sea salt particles.
- Surface sources for both dust and sea salt particles as functions of surface properties, wind speed, and soil humidity (diagnostic)
- Bin approach for the riming process
- Interfaced with the Los Alamos Sea Ice Model (CICE) (greatly improves the credibility of surface fluxes, and allow the realistic simulation of Arctic boundary layer clouds)

- These improvements may be important for the University of Athens developments…

Dust Effect on Precipitation

- Dust which can enhance CCN, GCCN, and IN concentrations can alter the dynamics of convective storms, the optical thickness of the anvils they produce, and surface rainfall.
- However, the impact of rainfall is complicated by cold-pool dynamics which in turn respond to the amounts of rainfall and the size-spectrum of raindrops.
- Thus we saw that rainfall increased due to dust at first whereas after several hours the accumulated rainfall decreased.

- *from* Recent advances in RAMS cloud microphysics and precipitation over-prediction. **William R. Cotton and Steve Saleeby**, Dept of Atmospheric Science, Colorado State University, RAMS Users Workshop, Ubatuba, Brazil, 2006

Urban Aerosol Effects on Precipitation

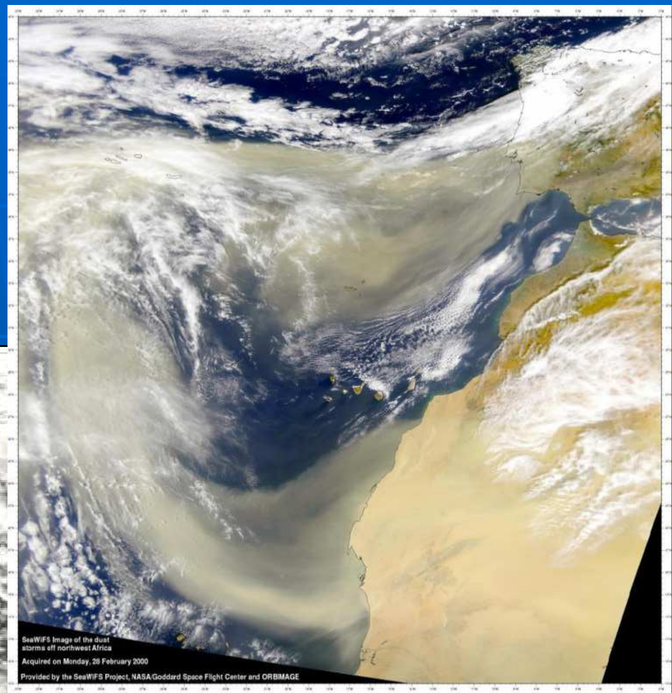
- Urban land-use has the biggest control on locations and amounts of precipitation
- Overall, both CCN and GCCN concentrations are important to cloud responses to varying aerosols.
- In supercooled clouds and deep convective clouds, variations in IN concentrations can also play an important role in governing storm dynamics and rainfall.
- Even in shallow boundary layer clouds, once aerosols effect the precipitation process, the cloud radiative properties can be modified in nonlinear ways.
- For deep convective clouds, the nonlinear interactions between varying aerosol amounts and cloud dynamics can lead to responses in terms of rainfall amounts that are quite unpredictable. Short term responses may increase rainfall whereas longer-term responses can decrease rainfall.

- *from* Recent advances in RAMS cloud microphysics and precipitation over-prediction. **William R. Cotton and Steve Saleeby**, Dept of Atmospheric Science, Colorado State University, RAMS Users Workshop, Ubatuba, Brazil, 2006

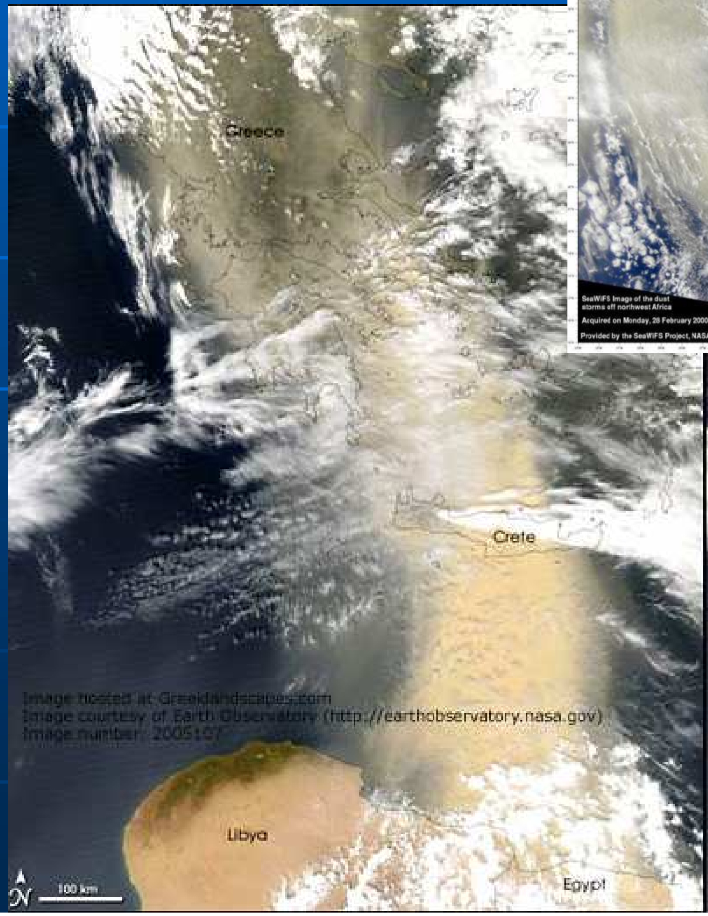
Aerosol Improvements

- ATMET is consulting with scientists at the University of Athens (Greece)
- Three important additions to RAMS:
  - Dust model
  - Sea salt model
  - Chemistry – photochemistry and aqueous phase (inline)
- Expected improvements:
  - Better cloud/precipitation simulation
  - Better visibility simulation
  - Boundary layer haze (hopefully)

Aerosol Improvements



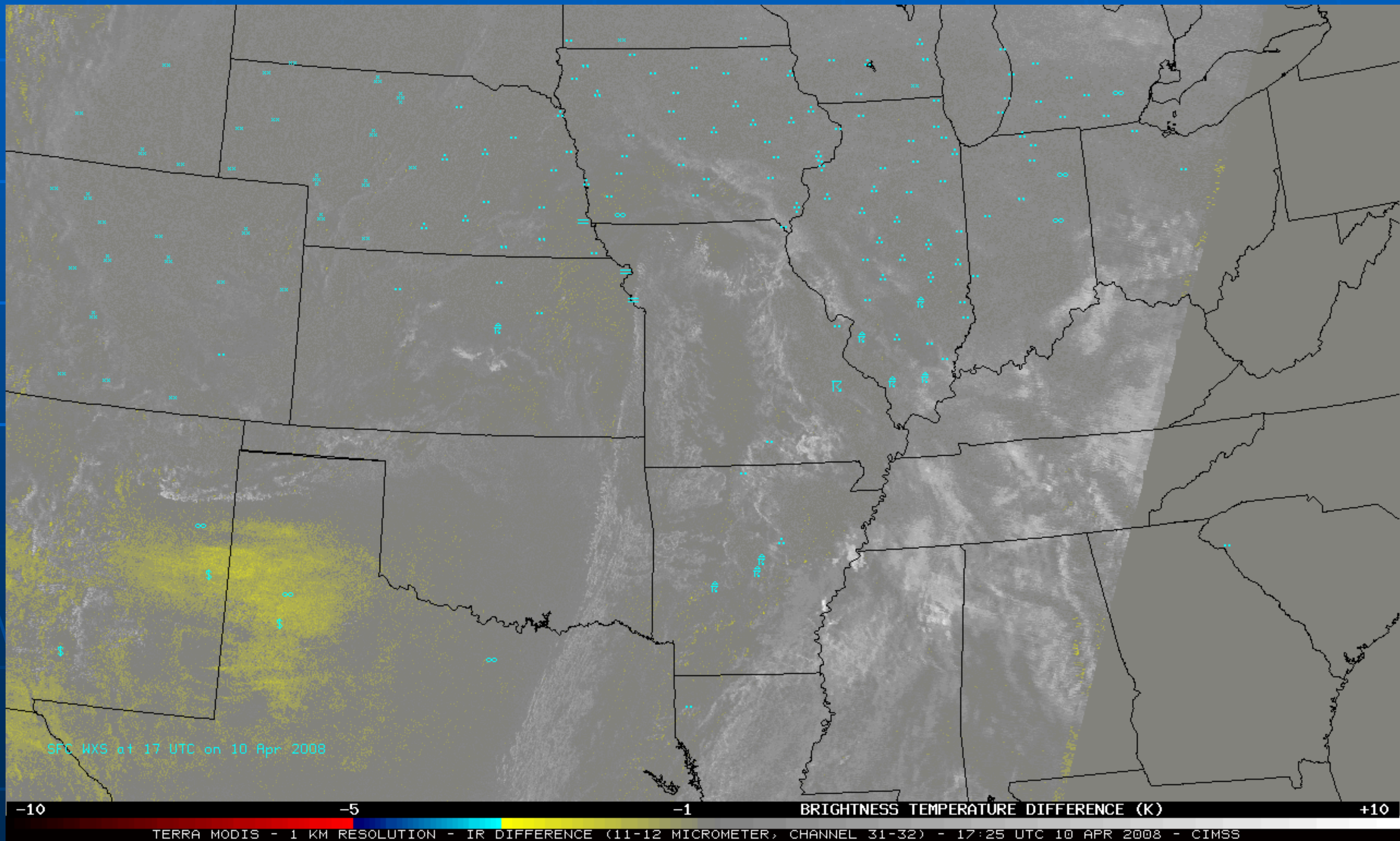
Do we really need a dust/salt model?



- Some dust can act as IFN
- Salt is an important source of hygroscopic CCN in many places

ATmospheric, Meteorological, and Environmental Technologies

It can happen here….



UNIVERSITY OF ATHENS

SCHOOL OF PHYSICS, DIVISION OF ENVIRONMENT AND METEOROLOGY

ATMOSPHERIC MODELING AND WEATHER FORECASTING GROUP

http://forecast.uoa.gr

ICLAMS

RAMS v6 new Model Development

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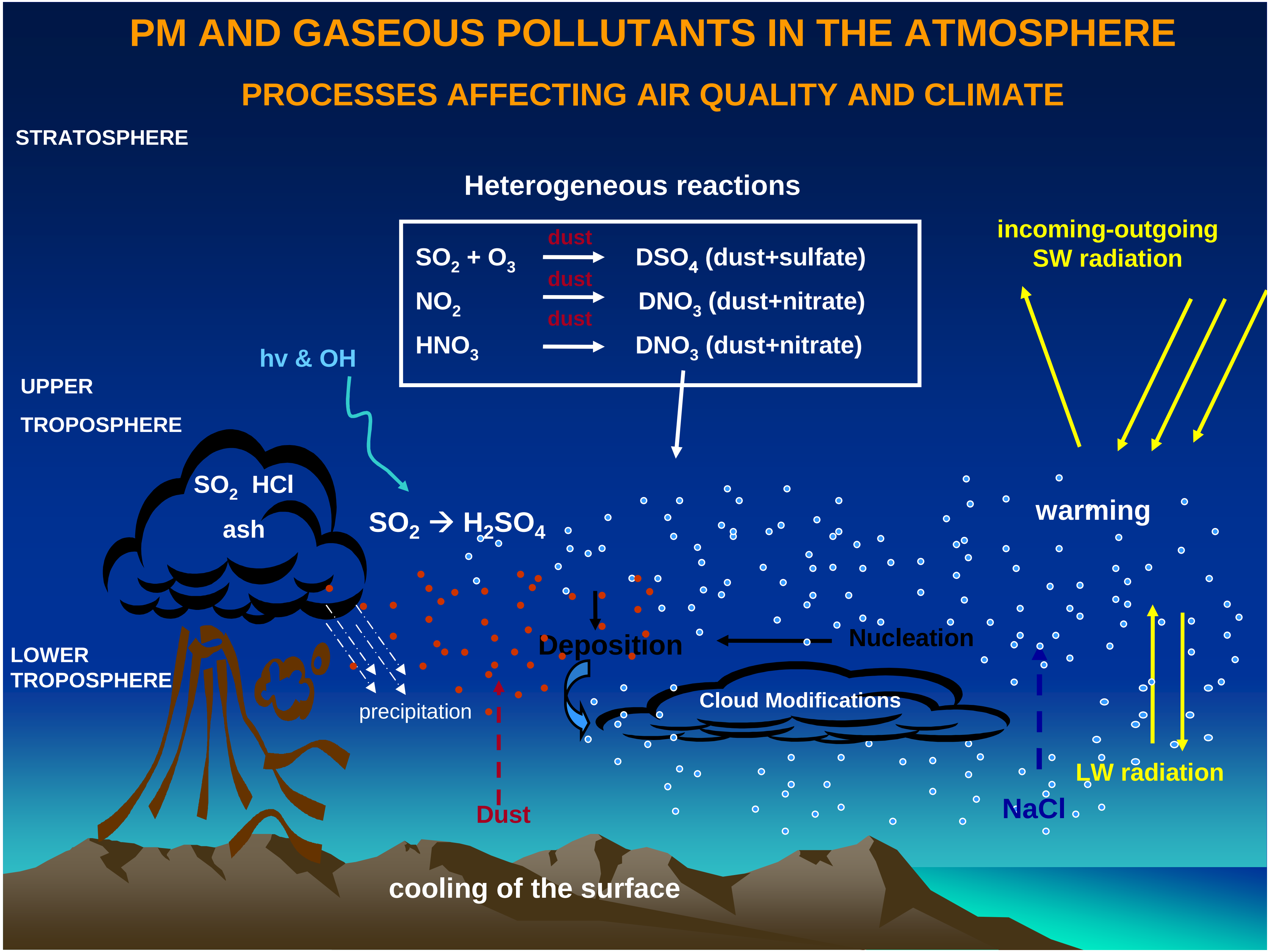
Some Effects of Soil Dust in the Atmosphere

- ✓ By scattering and absorbing solar radiation modifies the planetary albedo and reduces the amount of radiation reaching the surface
- ✓ By absorbing part of the IR radiation causes atmospheric heating
- ✓ By acting as CCN modifies the microphysical, micro-chemical and hence optical and radiative properties of clouds
- ✓ Aerosols can also decrease the cloud precipitation efficiency
- ✓ In combination with certain anthropogenic pollutants can work towards the formation of heavy rainfall
- ✓ Changes features on the terrestrial ecosystems (Reichholf,1986)
- ✓ Neutralizes acid rains (Hedin and Likens, 1996)
- ✓ It reduces visibility
- ✓ It affects air quality in urban areas (and not only)
- ✓ Dust deposition provides considerable quantities of bioavailable nutrients to ocean surface waters and the seabed
- ✓ Saharan dust aerosols influence the nutrient dynamics and biogeochemical cycling of both terrestrial and oceanic ecosystems
- ✓ There is evidence that dust may cause ocean cooling (Schollaert and Merrill, 1998)
- ✓ Dust contains appreciable quantities of iron, the addition of which to ocean waters may increase plankton productivity
- ✓ ....

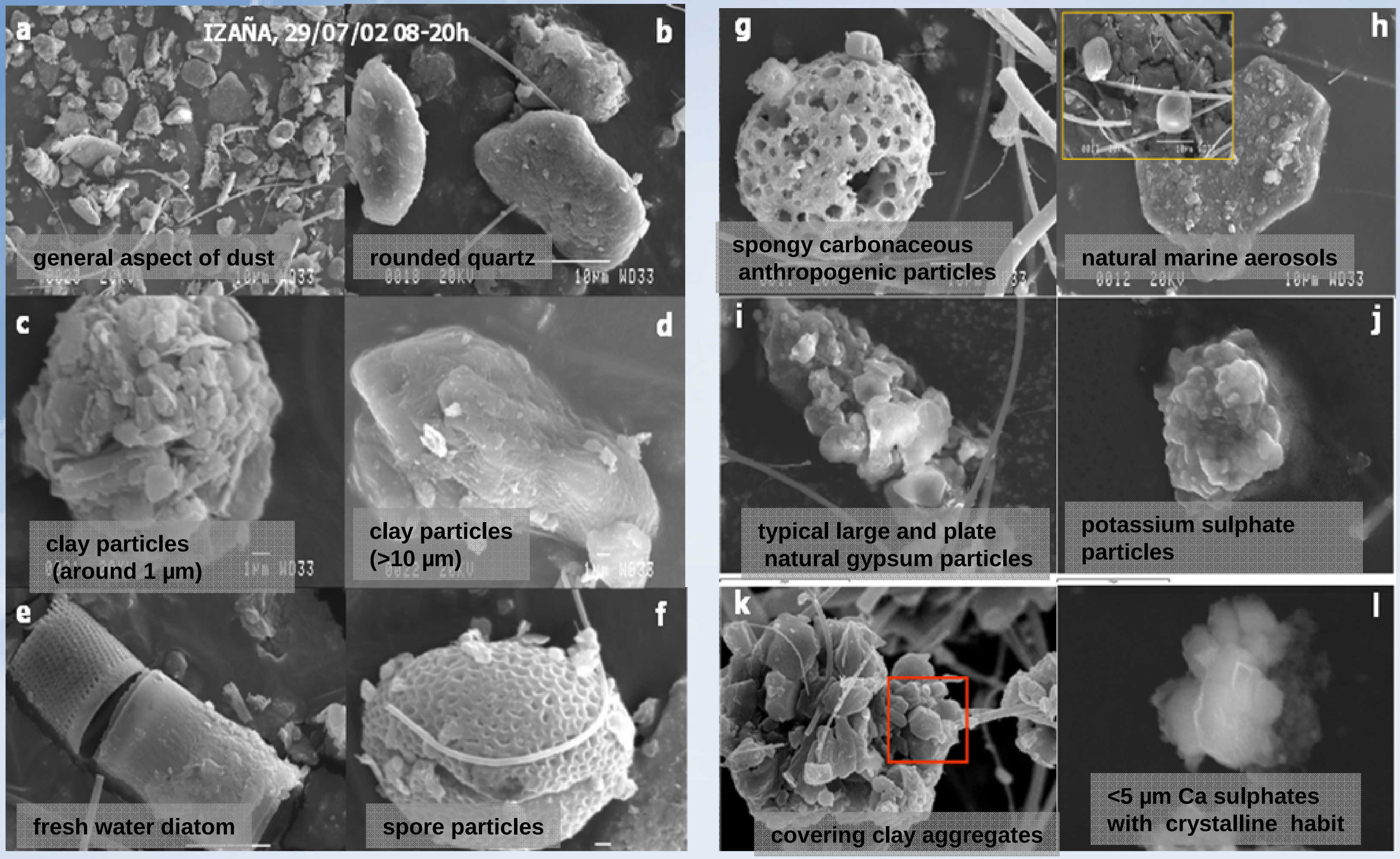


PM AND GASEOUS POLLUTANTS IN THE ATMOSPHERE
PROCESSES AFFECTING AIR QUALITY AND CLIMATE
STRATOSPHERE
Heterogeneous reactions
$SO_2 + O_3 \xrightarrow{dust}$ DSO_4 (dust+sulfate)
$NO_2 \xrightarrow{dust}$ DNO_3 (dust+nitrate)
$HNO_3 \xrightarrow{dust}$ DNO_3 (dust+nitrate)
incoming-outgoing
SW radiation
hv & OH
UPPER
TROPOSPHERE
SO_2 HCl
ash
$SO_2 \rightarrow H_2SO_4$
warming
Deposition
Nucleation
LOWER
TROPOSPHERE
Cloud Modifications
precipitation
LW radiation
Dust
NaCl
cooling of the surface

COEXISTENCE OF MINERAL DUST, SULFATES AND CLOUD DROPLETS

SEM analysis

Izaña | **Sta. Cruz de Tenerife**

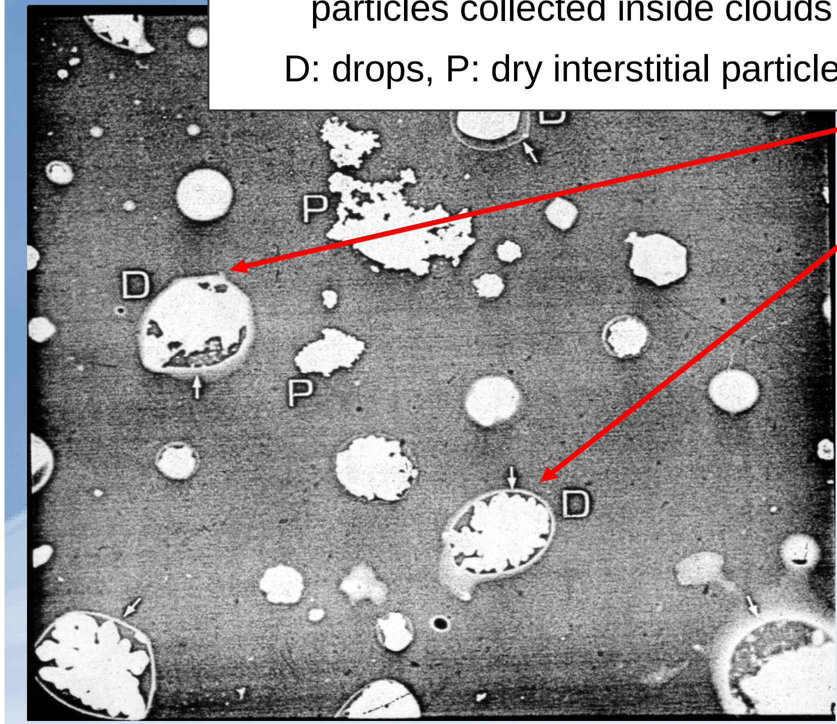


(Alastuey et al. 2005)

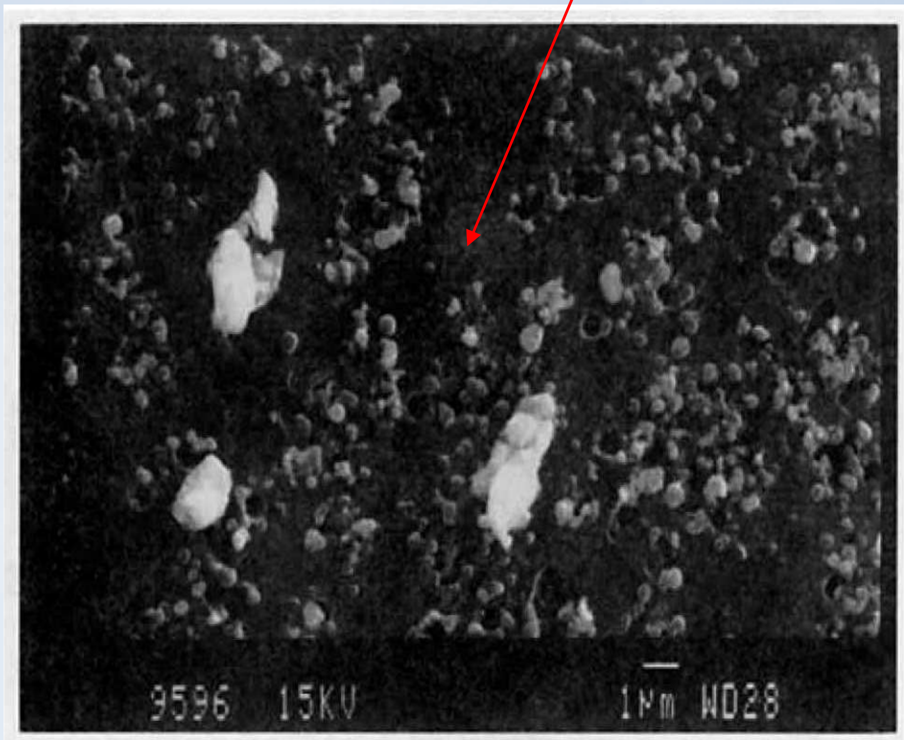
COEXISTENCE OF MINERAL DUST, SULFATES AND CLOUD DROPLETS

A photomicrograph of drops and aerosol particles collected inside clouds

D: drops, P: dry interstitial particles



A photomicrograph of desert mineral dust with small sulfate particles on its surface.



(Levin et al. 1996, 2006)

LINKS AND FEEDBACKS BETWEEN AIR QUALITY WEATHER AND CLIMATE

The links between air quality and meteorology (and regional climate) are many and not necessarily on one way

The feedbacks between the various processes are many and complicated

The existing modeling tools like SKIRON/Dust with CAMx are not able to describe some important feedbacks and especially aerosol – radiation – cloud and precipitation

At the framework of the CIRCE project an effort is devoted on developing the Integrated Community Limited Area Modeling System (ICLAMS) to study such processes

ICLAMS

ICLAMS development is on RAMS ver. 6 modeling system

RAMS is a multi-scale modeling system and can be configured to run with resolution from a few meters to tens of kilometers on a two-way interactive nesting mode

It has detailed cloud microphysical scheme with 8 microphysical categories, detailed surface parameterization and many other features that make it an advanced limited area meteorological model

The cloud microphysical scheme includes prognostic equations for mass mixing ratios of the various forms of water species.

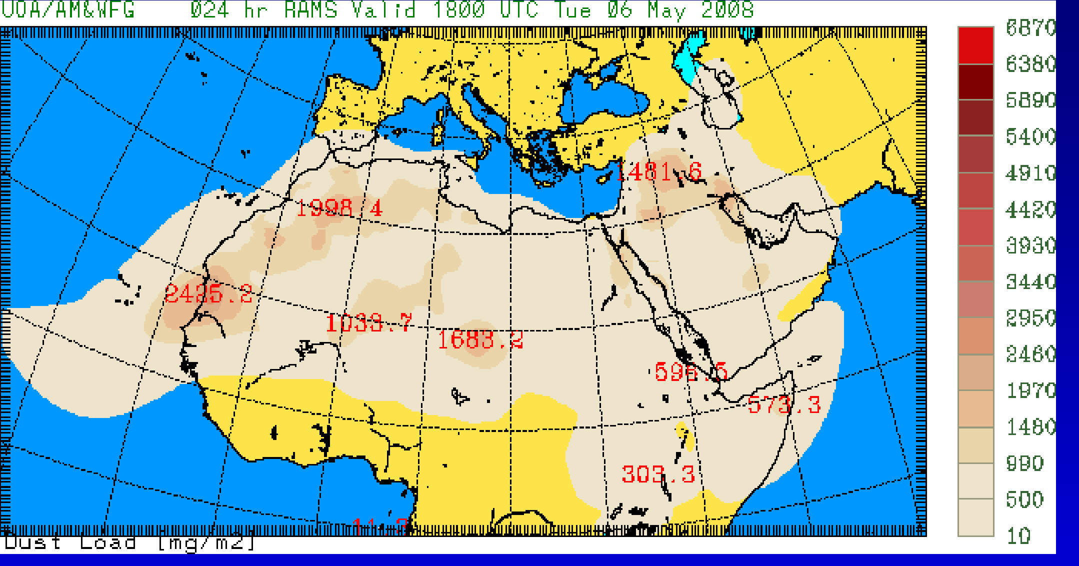
ICLAMS

The new model development includes the following features:

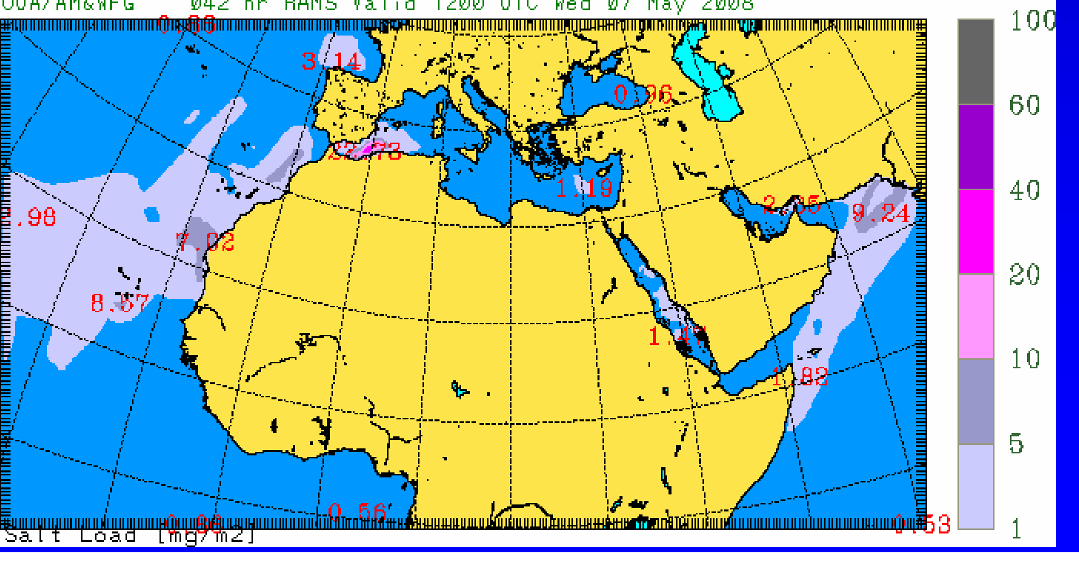
- **Dust cycle module following the formulation used in SKIRON/Dust with 8 dust bins following lognormal distribution Zender et al. (2003), Kallos et al., (2005, 2007).**
- **Sea salt production mechanism with 2 size bins following Gong et al., (1999).**
- **Gas and aqueous phase chemistry (SAPRC mechanism as implemented in CMAQ).**
- **Heterogeneous chemistry following ISOROPIA scheme and additional interactions with desert dust, sea salt and sulfates on a uniform environment.**
- **Impacts of aerosols and PMs on radiative transfer of the photochemically active bands.**
- **Visible and Infrared corrections due to aerosols and PMs.**
- **Treatment of CCN and GCCN as predictive quantities (4-D).**
- **All these new elements are directly coupled and executed together with the meteorological modules.**

ICLAMS MODEL OUTPUT

Dustload (mg/m2) 06MAY2008 1800 UTC



Saltload (mg/m2) 07MAY2008 1200 UTC



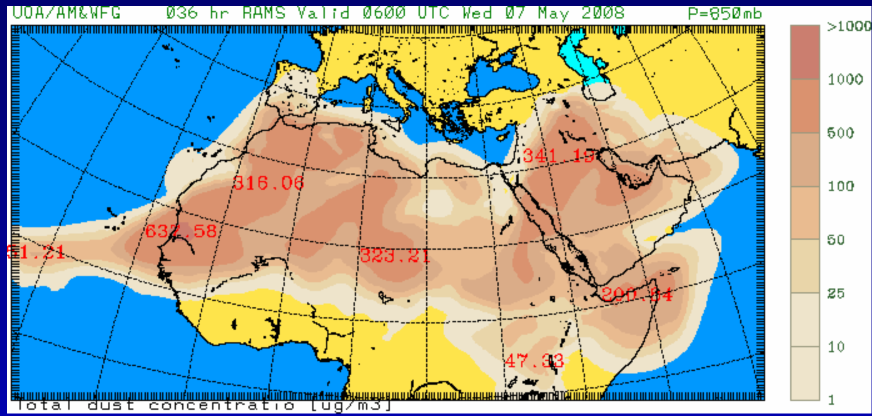
ICLAMS MODEL OUTPUT

Total dust concentration (ug/m3)

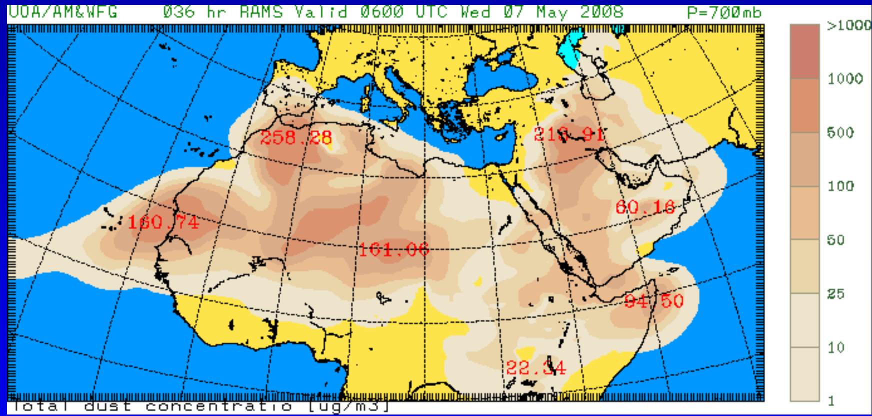
7MAY2008 0600 UTC

at

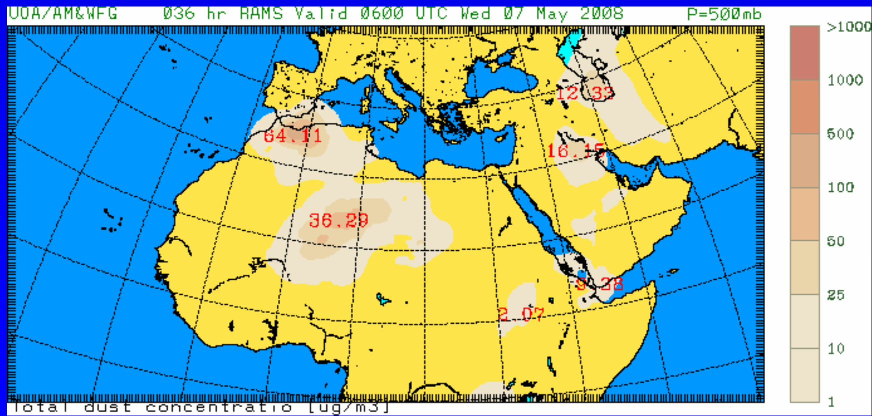
850 mb



700 mb

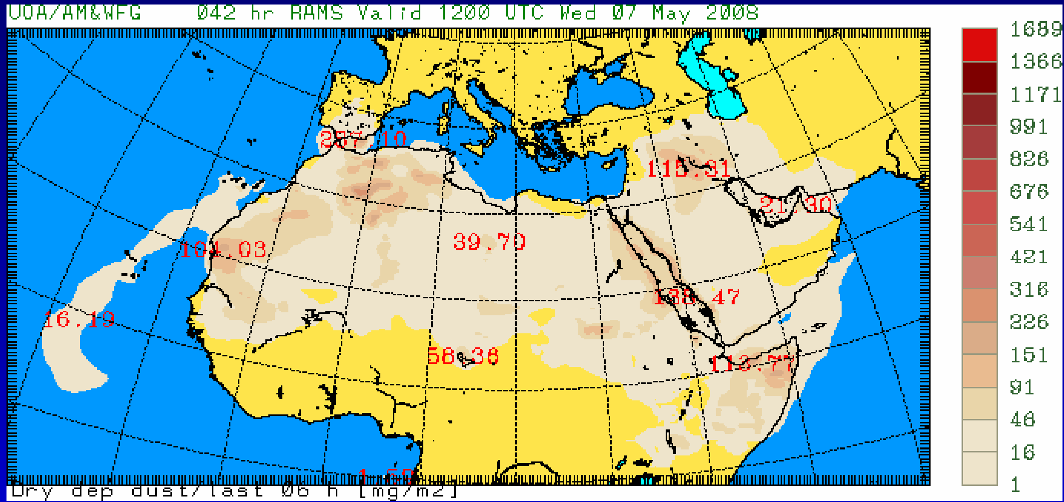


500 mb

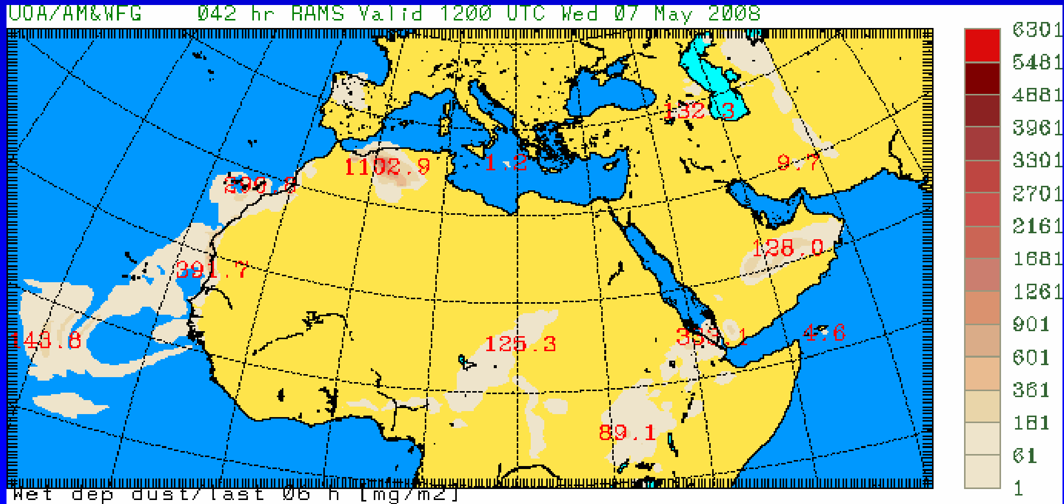


ICLAMS MODEL OUTPUT

6h accum. Dry Deposition (mg/m2) 07MAY2008 1200 UTC

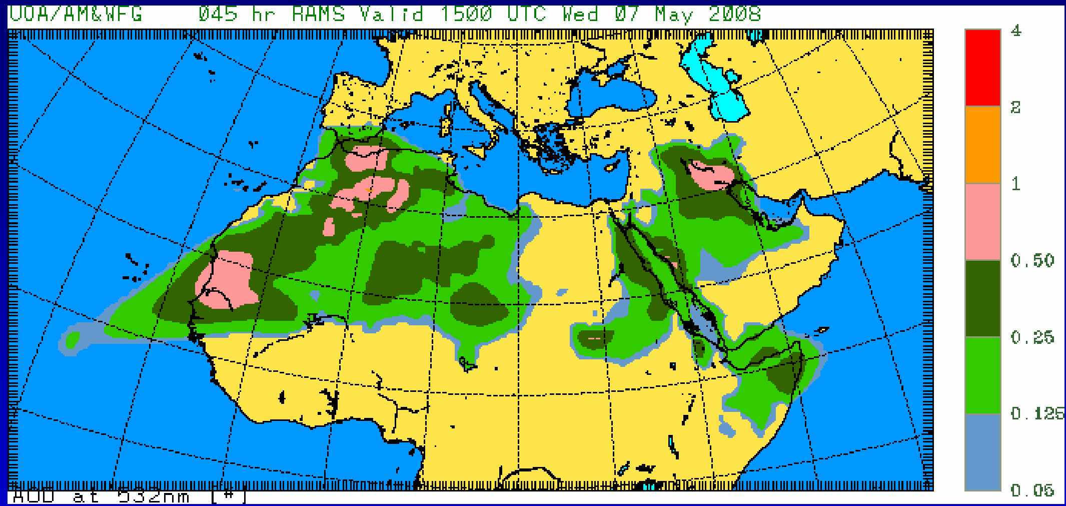


6h accum. Wet Deposition (mg/m2) 07MAY2008 1200 UTC

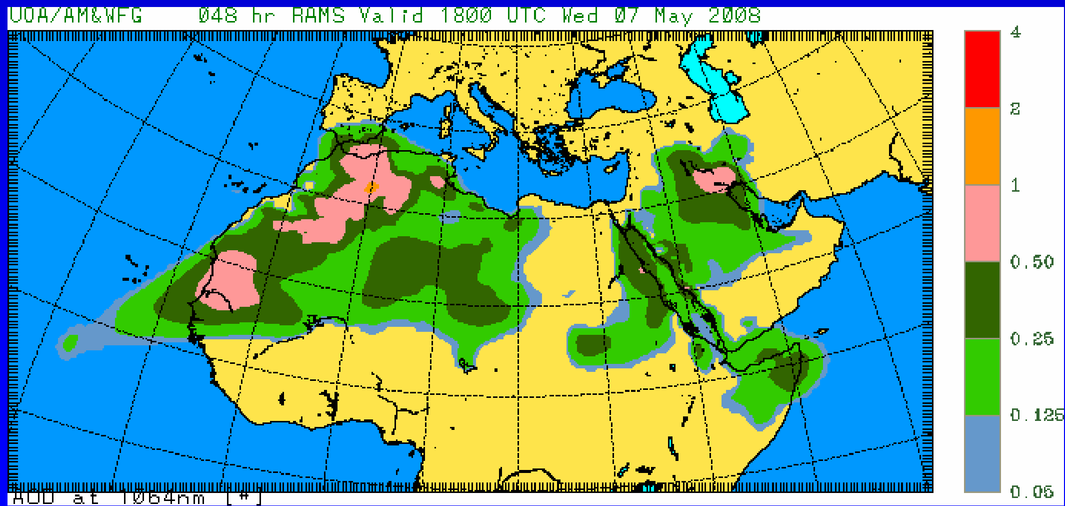


ICLAMS MODEL OUTPUT

Aerosol Optical Depth at 532nm 07MAY2008 1500 UTC



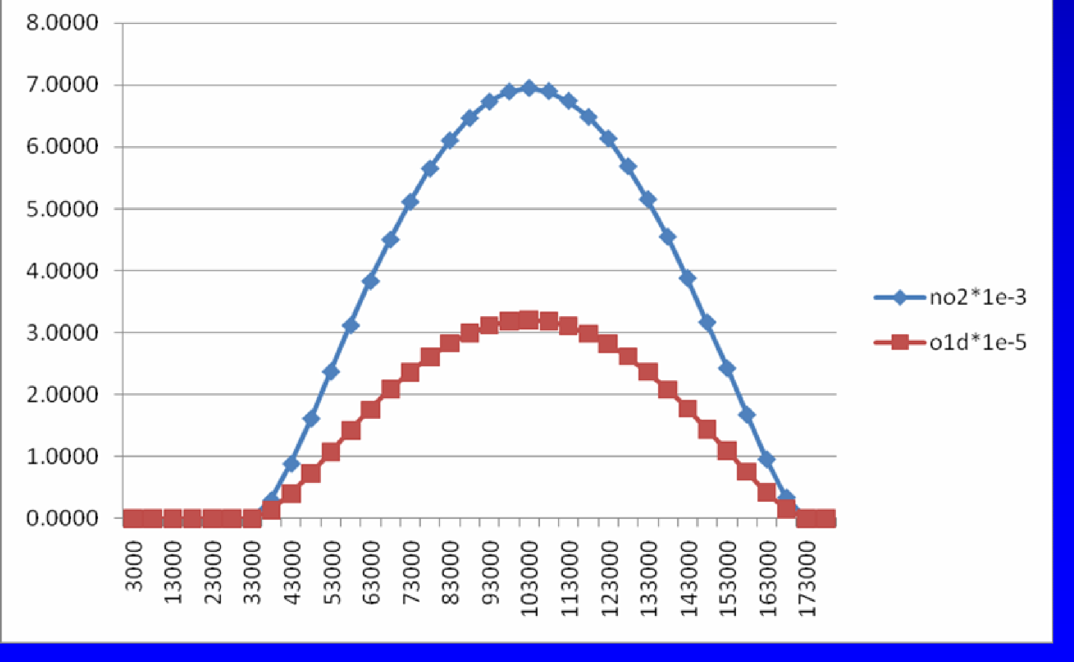
Aerosol Optical Depth at 1064nm 07MAY2008 1500 UTC



ICLAMS MODEL OUTPUT
Photolysis Rates

- **Photolysis rates calculated online with a direct coupling with the radiation transfer scheme.**
- **Correction for altitude, temperature and pressure on sensitive photochemical species.**
- **Direct cloud effect on radiation and photolysis rates**

Daily variability of the photolysis rates of NO2 and O1D for 17 May 1999, Crete, Greece



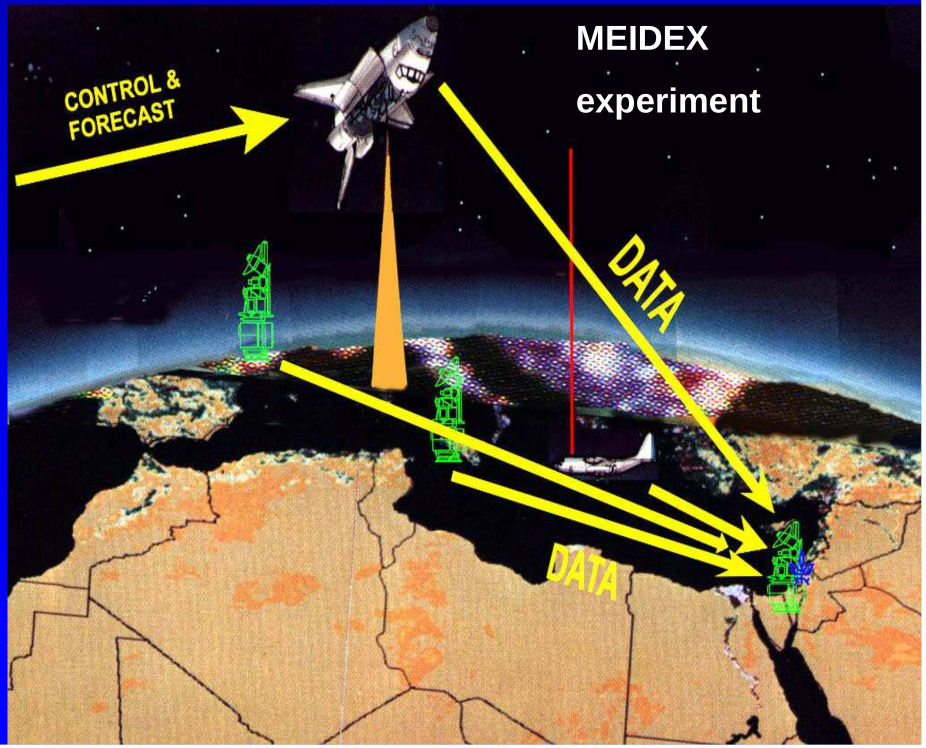
MEIDEX TEST CASE

- **On 28 January 2003, a dust storm passed over the north east Mediterranean region.**
- **On 29 JAN 2003 heavy rain and hail dispersed over the Middle East coastline and a few km inland.**
- **Flood events and agricultural disasters were reported.**
- **Airborne measurements of this episode were obtained during the Mediterranean Israeli Dust Experiment (MEIDEX)**

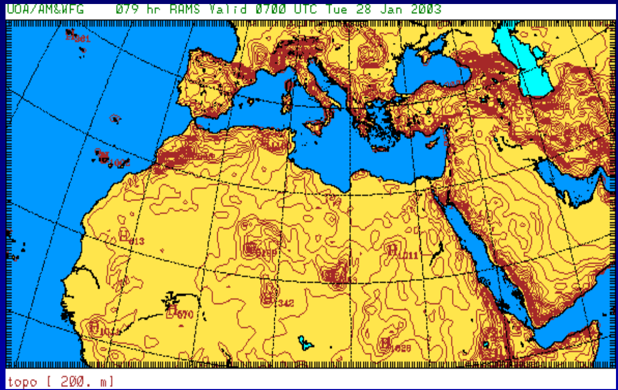
RAMS6 with dust and sea salt modules

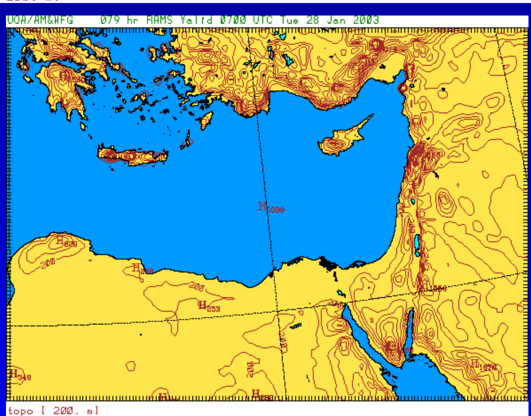
1st case: Natural particles are treated as passive tracers. User specified constant CCN #.

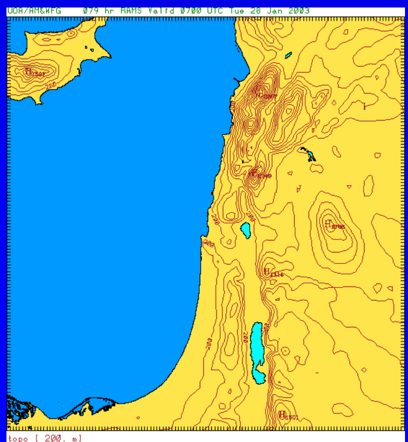
2nd case: Dust plume and sea-salt spray interact with clouds. CCN and GCCN prognostic (from dust and sea salt concentrations and size distribution.



MODEL SETUP







RAMS6.0 with:

DUST MODULE (Zender at al., Marticorena and Bergameti)

8 Bin lognormal dust particles distribution - Dust cycle

SEASALT MODULE (Gong et al.)

2 Bin lognormal salt particles distribution - Seasalt cycle

DOMAIN SETUP

3 grids (36km-12km-4km) , 31 vertical levels, 120 hours run

Initial and boundary conditions – NCEP 1deg GFS analysis data

REFERENCE RUN (1^{st} case)

ICLOUD=5 (Constant # of CCN)

Dust and Salt particles do not interact with the rest of the model

TEST RUN (2^{nd} case)

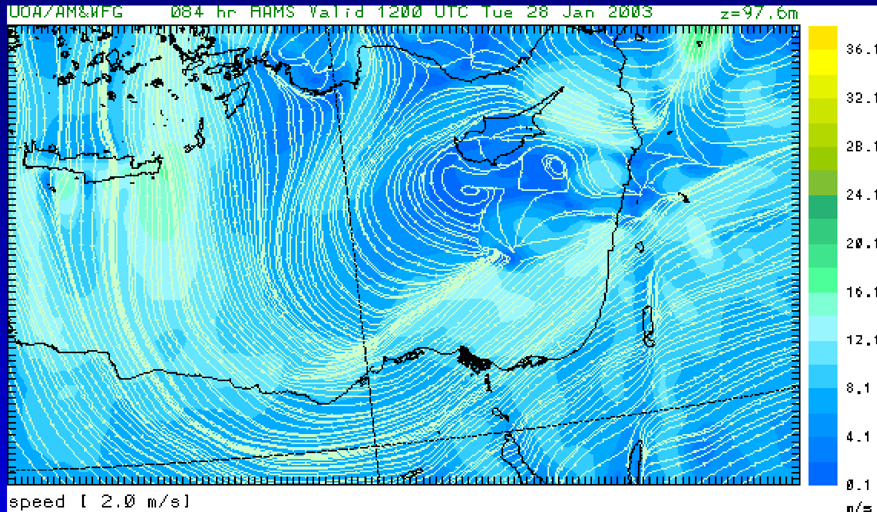
ICLOUD=7 (3-D prognostic CCN and GCCN field)

Particles serve as efficient cloud condensation nuclei (CCN).

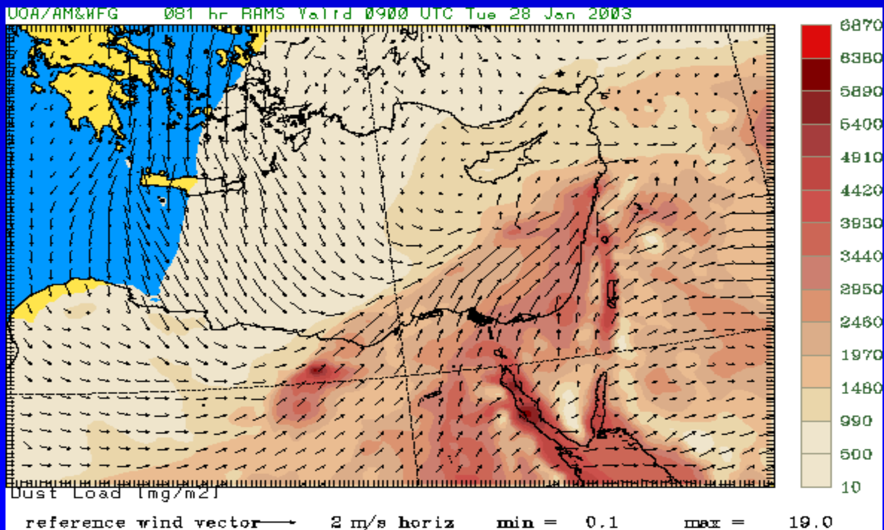
LARGE SCALE FEAUTURES

- On 28 Jan 2003 a cold cyclone moved from Crete through Cyprus accompanied by a cold front .
- A second air mass transported dust particles from NE Africa over the sea towards the Israeli coast.

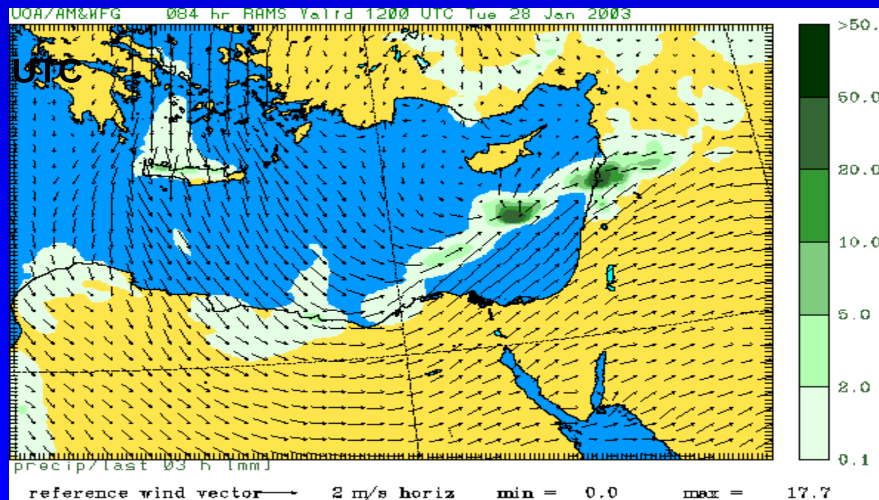
Wind speed 28JAN2003 1200UTC



Dust load 28JAN2003 0900 UTC



3h accumulated precipitation 28JAN2003 1200 UTC



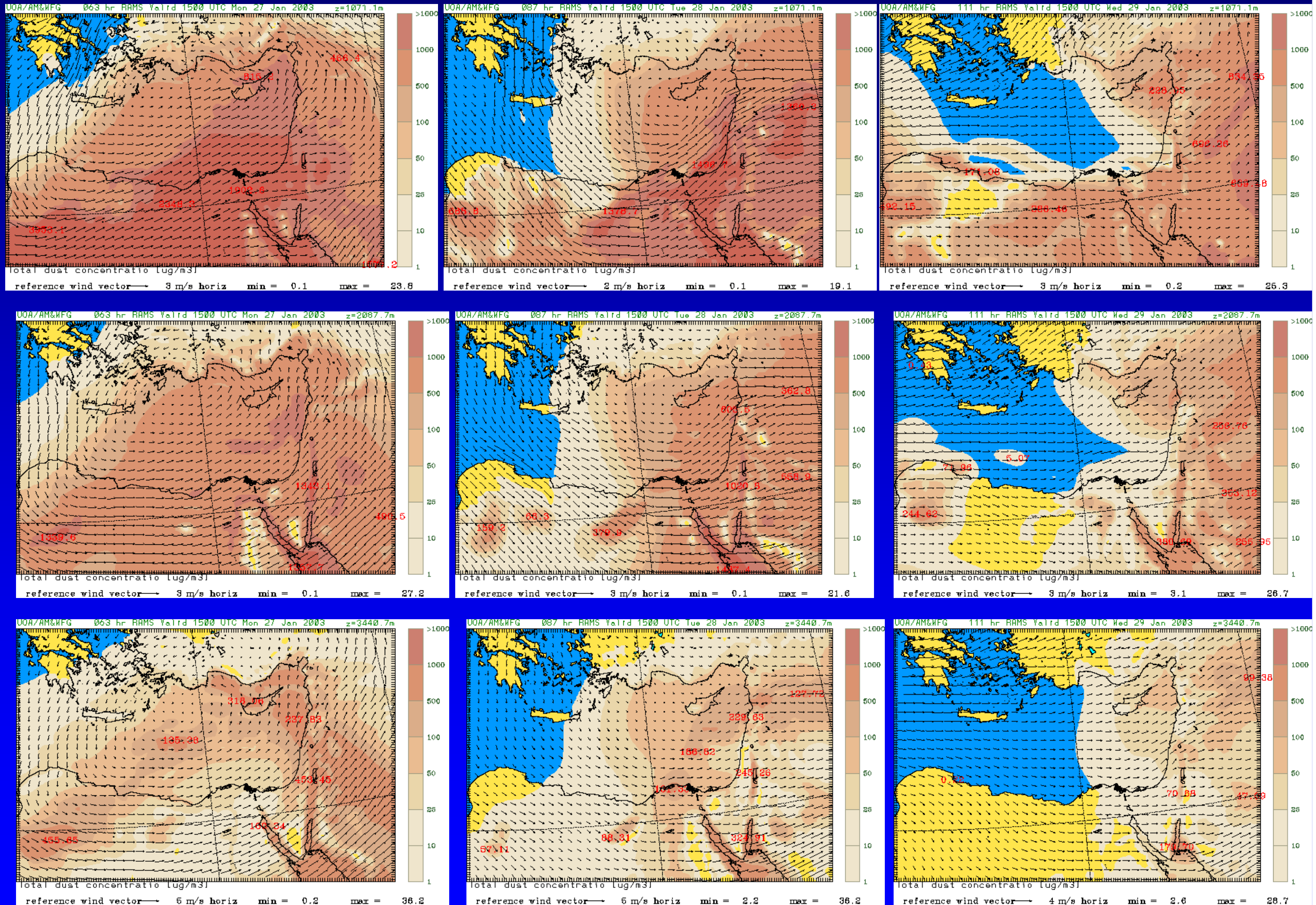
DUST CONCENTRATION at 1500UTC (all bins)

27JAN2003 1500 UTC | **28JAN2003 1500 UTC** | **29JAN2003 1500 UTC**

1071 m
6th model level

2087 m
9th model level

3440 m
12th model level



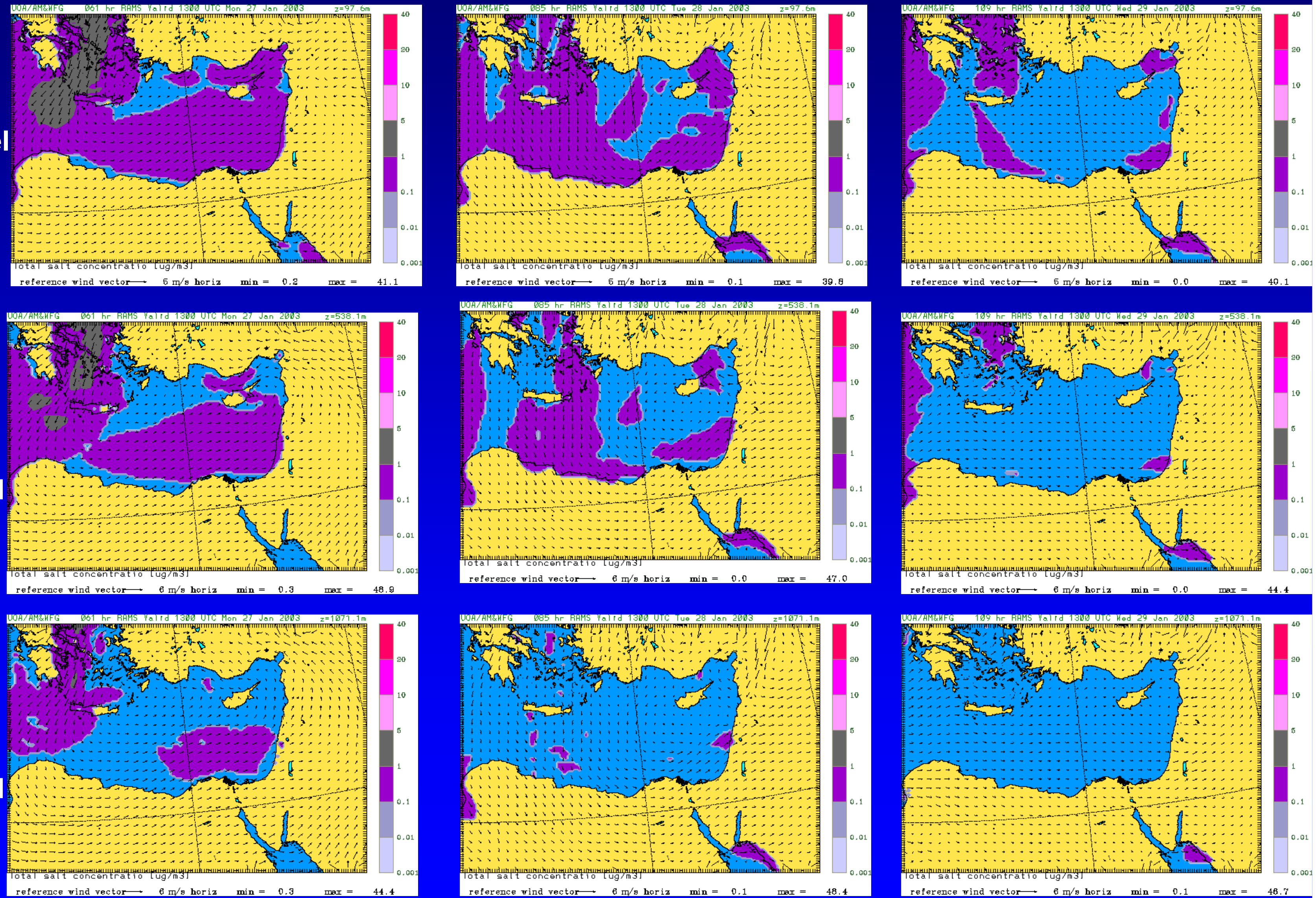
SEA SALT CONCENTRATIONS at 1500 UTC (both bins)

27JAN2003 | **28JAN2003** | **29JAN2003**

97 m
2nd model level

530 m
4th model level

1071 m
6th model level

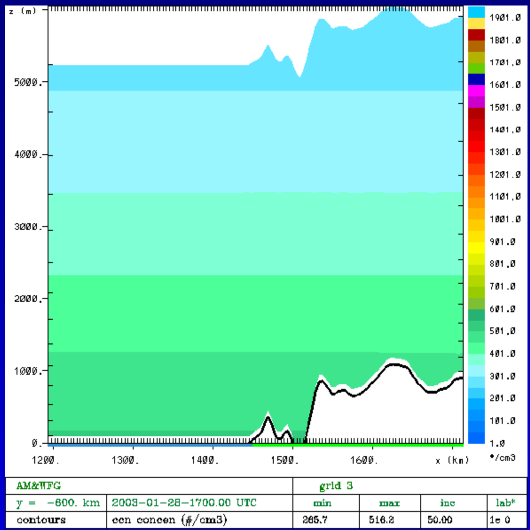


RAMS CCN VERTICAL DISTRIBUTION

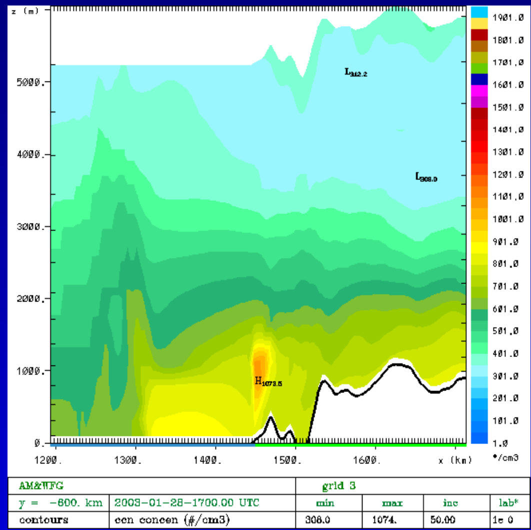
Constant CCN field

Prognostic 3D CCN field

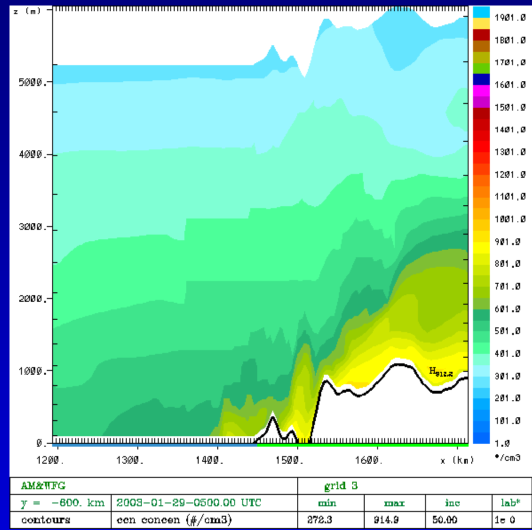
CCN concentration (#/cm³)



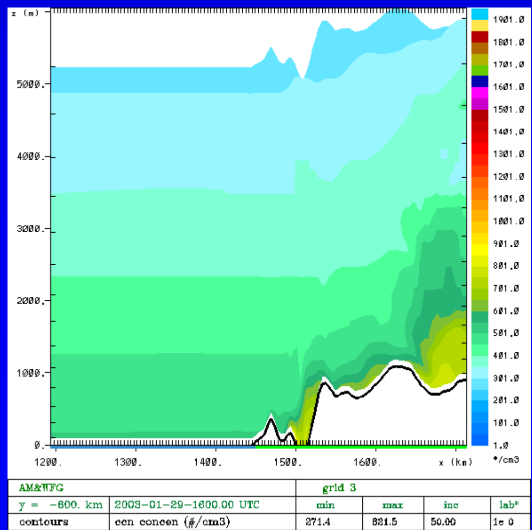
CCN concentration 28JAN2003 1700 UTC



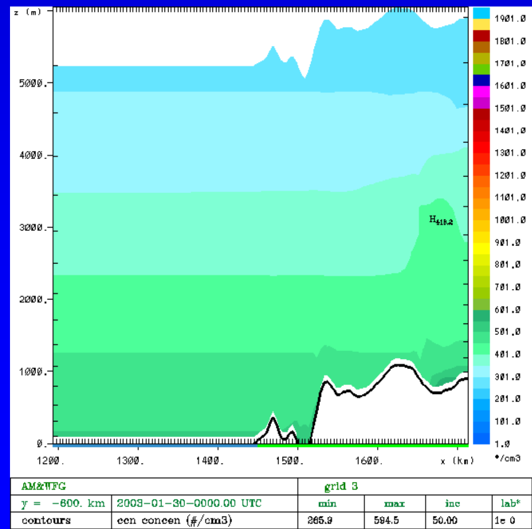
CCN concentration 29JAN2003 0500UTC



CCN concentration 29JAN2003 1600UTC



CCN concentration 30JAN2003 0000UTC



Summary – Conclusions

- ✓ The naturally-produced particulate contributes significantly on air quality degradation, especially in Southern Europe and of course, North Africa.
- ✓ Violations of air quality standards due to high PM concentrations in South European cities are associated to Saharan dust transport episodes for 30-70% of the cases, depending on the location.
- ✓ Desert dust anti-correlates with O3 (reduction of 1-6% at the surface due to shading).
- ✓ Of course, dust affects meteorology by reducing the surface heating and warming mid-tropospheric layers leading in stabilization.
- ✓ Although, these processes have not simple links between them.

ACKNOWLEDGEMENTS

This work is funded by EU :

project CIRCE

Eurocontrol

EUROPEAN COMMISSION

Conclusion

Lot's of work… so little time…

Aerosol Improvements

- Dust model
  - Fully prognostic, 8 size bins
  - Surface source terms
  - Dry and *wet* deposition
  - Surface source and sinks handled in a similar manner as sensible heat flux is treated relative to temperature
  - Dust concentration used as source for prognostic CCN

Aerosol Improvements

- Sea-salt model
  - Important source of hygroscopic CCN in many places
  - Fully prognostic, 2 size bins
  - Surface source terms
  - Dry and *wet* deposition
  - Surface source and sinks handled in a similar manner as sensible heat flux is treated relative to temperature
  - Salt concentration used as source for prognostic CCN

Aerosol Improvements

- Chemistry
  - SAPRAC mechanism as implemented in CMAQ
  - ~72 total species, subsets can be used depending on application
  - Surface source terms
  - Dry and *wet* deposition
  - Aqueous phase contributes to production of GCCN